Search for new physics in triple top quark events at CMS

Manuel Iglesias Alonso
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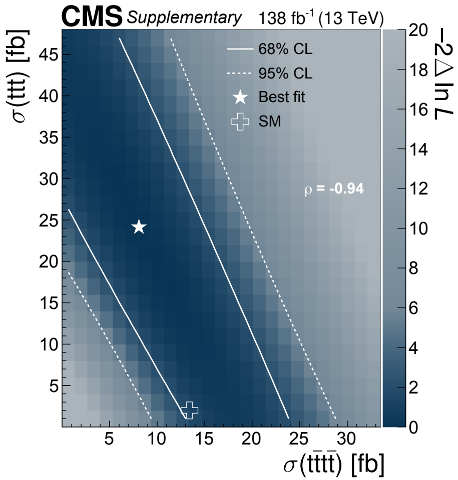
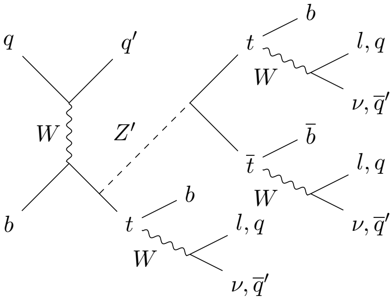
Triple top quark events



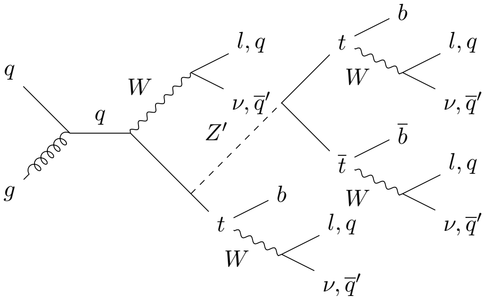
- Top quark:
  - Highest mass of all the fundamental particles.
  - High Yukawa coupling with Higgs boson.
  - Beyond the SM particles might interact with top quarks preferentially due to its high mass.
- Cross section 3t (Z') $>$ 4t (Z').
- Difference between the SM prediction and the experiment result.

Triple top quark events

t channel

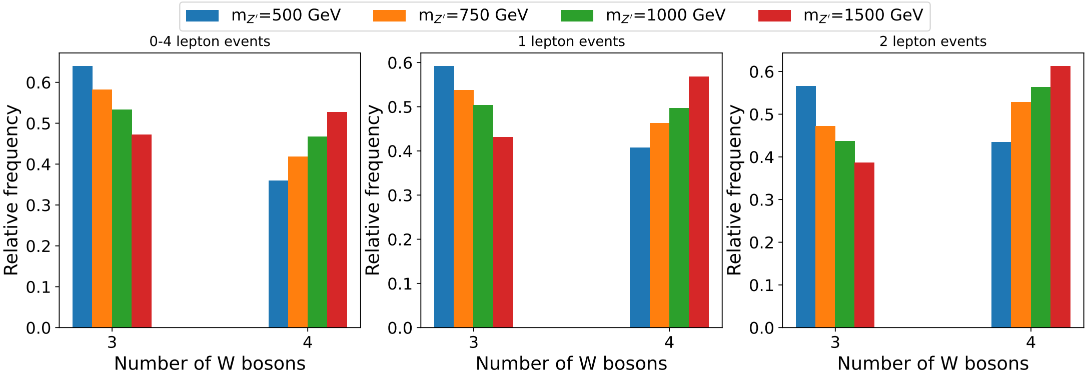


tW channel



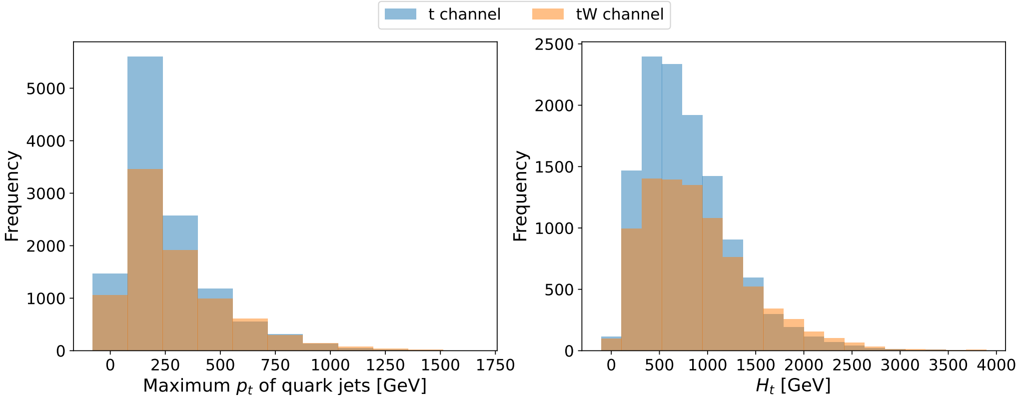
- We consider top-philic model for Z’ boson.
- Number of on shell W bosons is used to distinguish between both production channels.

Dependence on the Z' boson mass



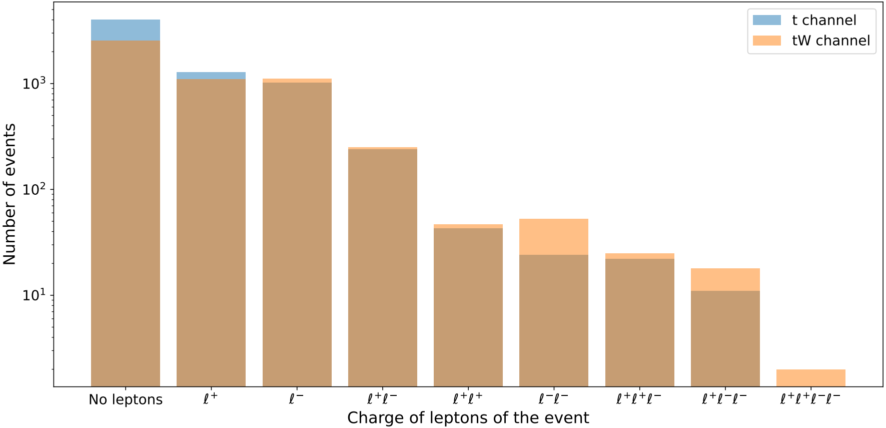
- The proportion of events of events in the tW channel increases both with the Z' mass and the number of leptons.

Comparison of the production channels



- There are usually higher p_T jets in the tW channel.

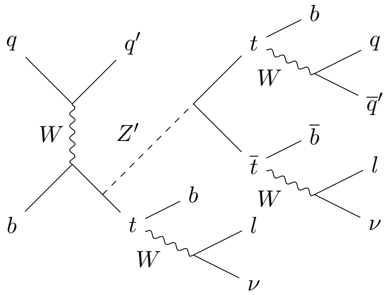
Comparison of the production channels



> Number of events decreases with number of leptons, asymmetry between channels.

Kinematic fitting

t channel



- Reconstruction of Z’ prime mass using kinematic fitting (Lagrange multipliers)
- Event selection:
  - t channel
  - 3 matched top quarks
  - 2 leptons with the same charge
  - At least 3 b-tagged jets
- Constraints:
  - $m(q,q') \overset{!}{\approx} m_W$
  - $m(q,q',b) \overset{!}{\approx} m_t$
  - $m(\ell,\nu) \overset{!}{\approx} m_W$
  - $m(\ell,\nu,b) \overset{!}{\approx} m_t$
  - $p_T^{\text{miss}} \overset{!}{=} \sum_\nu p_T^\nu$

Objective function

```python
#transverse momentum conservation constraints
chi2 = ops.square((met.px()-neutrino1.px()-neutrino2.px())/10.)
chi2 += ops.square((met.py()-neutrino1.py()-neutrino2.py())/10.)

#bjet-bquark resolution
chi2 += ops.square((bjet1.pt()-bquark1.pt())/50.)
chi2 += ops.square((bjet1.phi()-bquark1.phi())/0.2)
chi2 += ops.square((bjet1.eta()-bquark1.eta())/0.2)
chi2 += ops.square((bjet2.pt()-bquark2.pt())/50.)
chi2 += ops.square((bjet2.phi()-bquark2.phi())/0.2)
chi2 += ops.square((bjet2.eta()-bquark2.eta())/0.2)
chi2 += ops.square((bjet3.pt()-bquark3.pt())/50.)
chi2 += ops.square((bjet3.phi()-bquark3.phi())/0.2)
chi2 += ops.square((bjet3.eta()-bquark3.eta())/0.2)

#mass constraints
chi2 += ops.square((wbosonl1.mass()-80.4)/1.)
chi2 += ops.square((wbosonl2.mass()-80.4)/1.)
chi2 += ops.square((wbosonh.mass()-80.4)/1.)
chi2 += ops.square((topl1.mass()-172.5)/2.)
chi2 += ops.square((topl2.mass()-172.5)/2.)
chi2 += ops.square((toph.mass()-172.5)/2.)

chi2 = ops.reduce_sum(chi2)
```

$$
\chi^2 = \left(\frac{p_x^{\text{miss}} - p_x^{\nu_1} - p_x^{\nu_2}}{\sigma_x^{\text{miss}}}\right)^2 + \left(\frac{p_y^{\text{miss}} - p_y^{\nu_1} - p_y^{\nu_2}}{\sigma_y^{\text{miss}}}\right)^2 +
$$

$$
\sum_{i=1,2,3} \left(\frac{p_T^{b_i,\text{adj}} - p_T^{b_i,\text{meas}}}{\sigma_{p_T}^{b_i}}\right)^2 + \left(\frac{\eta^{b_i,\text{adj}} - \eta^{b_i,\text{meas}}}{\sigma_\eta^{b_i}}\right)^2 +
$$

$$
\left(\frac{\phi^{b_i,\text{adj}} - \phi^{b_i,\text{meas}}}{\sigma_\phi^{b_i}}\right)^2 +
$$

$$
\sum_{j=1,2,3} \left(\frac{m_{W_j}^{\text{reco}} - m_W}{\sigma_m^{W_j}}\right)^2 + \left(\frac{m_{t_j}^{\text{reco}} - m_t}{\sigma_m^{t_j}}\right)^2
$$

Tensorflow

```
met = PtPhiEtaMassVector.makeTensor('met',NCOMB)
neutrino1 = PtPhiEtaMassVector.makeTensor('neutrino1',NCOMB)
```

- We (mis)use tensorflow to work with 4-vectors and their operations.

- Created for ML purposes.
- Well-optimized library for efficient calculations.
- Helps to deal with the big amount of variables and the minimization process thanks to backpropagation.

```
class PtPhiEtaMassVector(P4Vector):
    def __init__(self,name,pt,phi,eta,mass,tensor=None):
        P4Vector.__init__(self,name)
        self._pt = pt
        self._phi = phi
        self._eta = eta
        self._mass = mass
        self._tensor = tensor
```

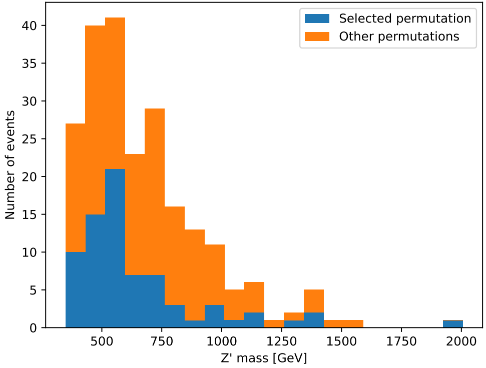
Main problems in kinematic fitting

- Too many degrees of freedom. Two steps:
  - Adjust of neutrinos solving exactly 6 equations with 6 variables.
  - Use Lagrange multipliers adding the b jets variables.

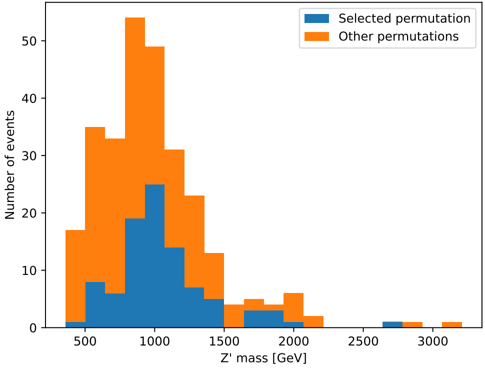
- Combinatorics:
  - 3 b jets must be assigned to 3 decaying top quarks.
  - 3 W bosons but only 2 come from Z'.
  - Total: 18 combinations:
    - b jets are assigned when solving the equations for neutrinos (6 equations for each combination).
    - Best results when using the W boson that decays hadronically and the one that decays to the lepton with lowest p_T to reconstruct Z'.

Results

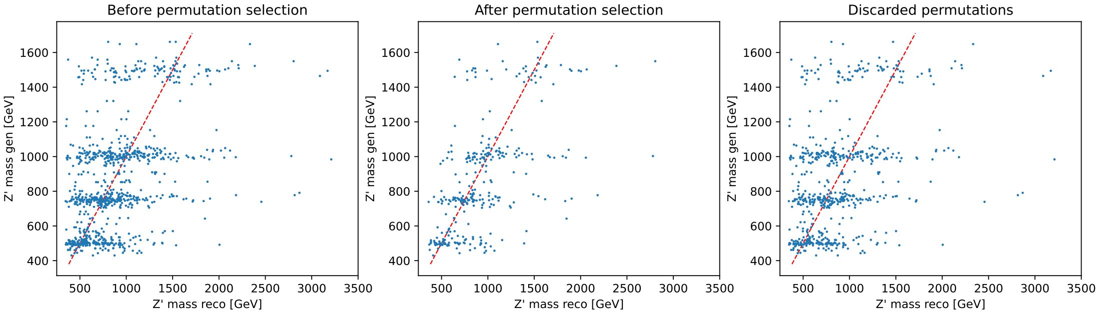
$\mathbf{m_{Z'} = 500\ GeV}$



$\mathbf{m_{Z'} = 1000\ GeV}$



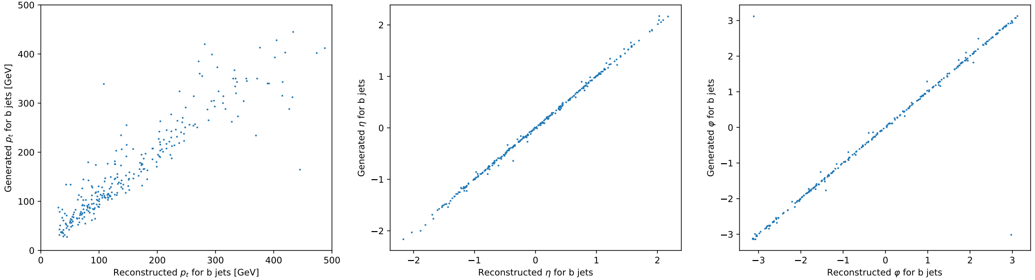
Results



> Mass reconstruction and permutation selection is quite good.

Results

- Correlation between properties at *gen* and *reco* level is not perfect.
- Example for b jets:



Summary

- We have studied triple top quark events, which have a greater cross section than the ones with 4 top quarks.
- There are differences in the properties of the particles involved in the t and tW channels, but the relative frequency underlines the interest on studying both.
- We have checked that kinematic fitting is a relevant tool for mass reconstruction.
- Tensorflow has a great potential for problems with many variables.
- This project has involved some ground work that can be applied later to bigger ones.