Overview of the Top FC Analysis

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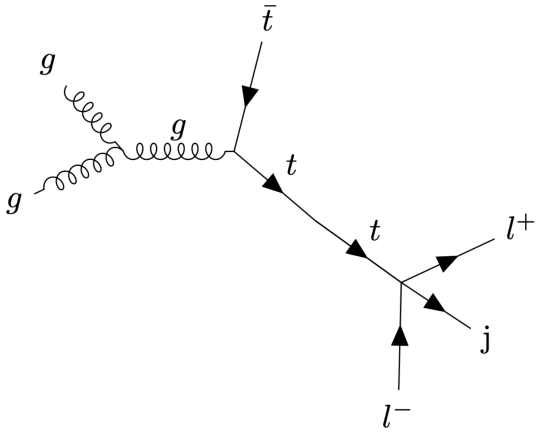
Introduction

- 3M ttbar and tW signals with separate couplings (S, V, and T) are generated. All the variables are computed and the trees are fed to the classifiers.
- Several classifiers are trained and still Neural net shows the best performance in terms of accuracy and ROC curve.
- Signal regions are defined based on the NN weights (using AMS method).
- Roostat and Pyhf statistical packages are used to compute z-score, p-values and upper limits.

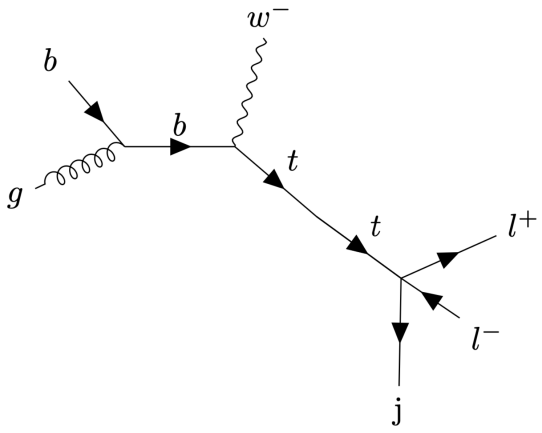
Flavor Changing in Top sector

In this analysis we looking for FC ($t \to u$ or $t \to c$) in top sector as the heaviest quark which may be an indicator of new flavor physics.



ttbar

- Starting with **ttbar**, targeting **final states** with three leptons (a pair of OP) and at least two jets with one b-tagged
- The leading potential backgrounds are $t\bar{t}, tZ, WZ, ZZ$

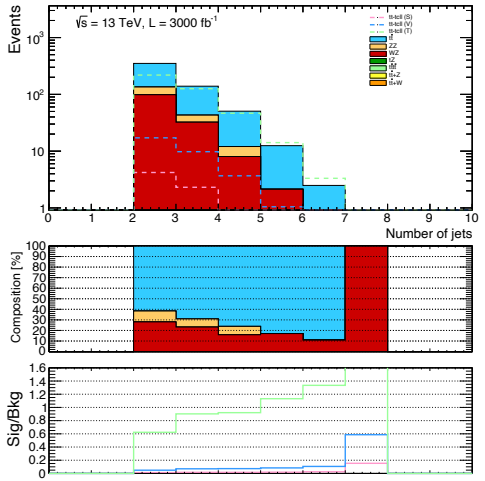


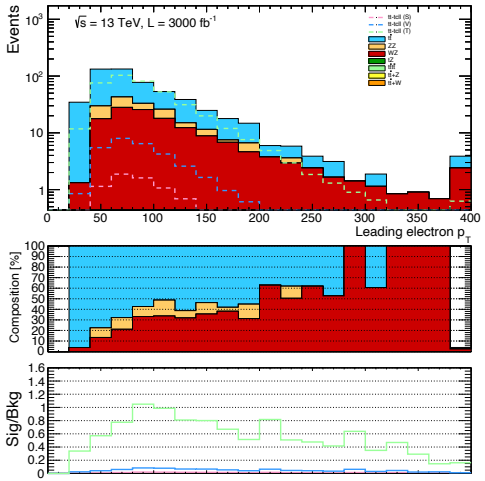
tW

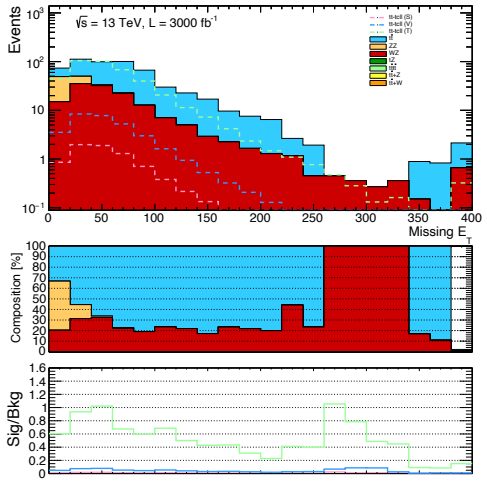
- Next channel **tW**, targeting **final states** with three leptons (a pair of OP) and at least two jets
- The leading potential backgrounds are tZ, WZ, ZZ

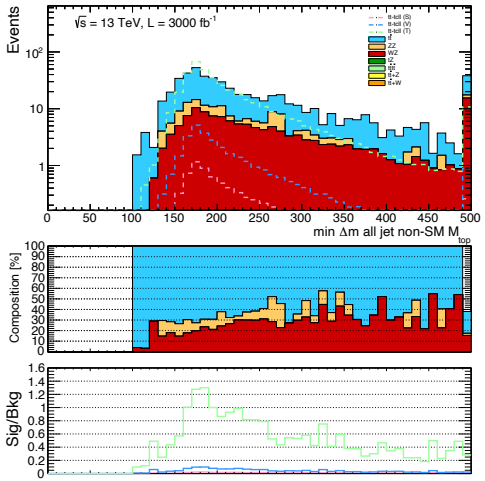
ttbar-charm couplings distributions

Higher cross sections for tensor coupling

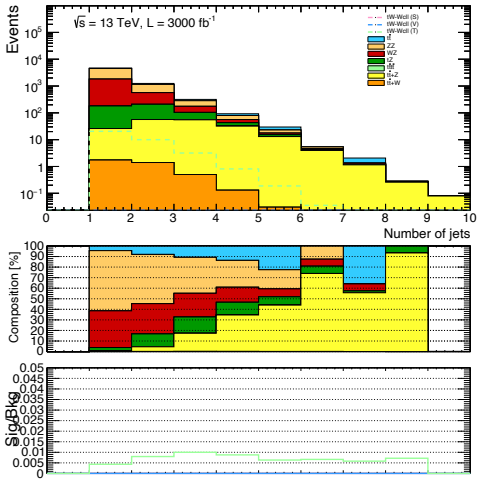


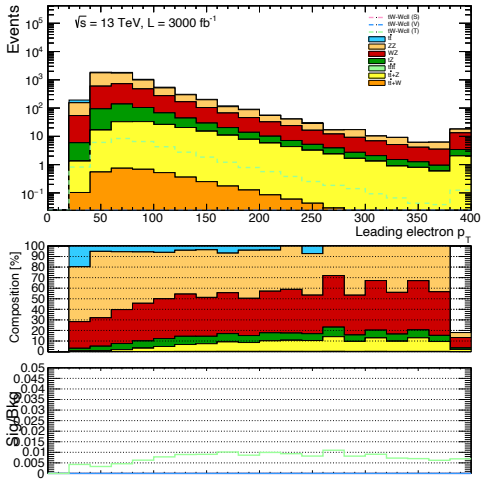


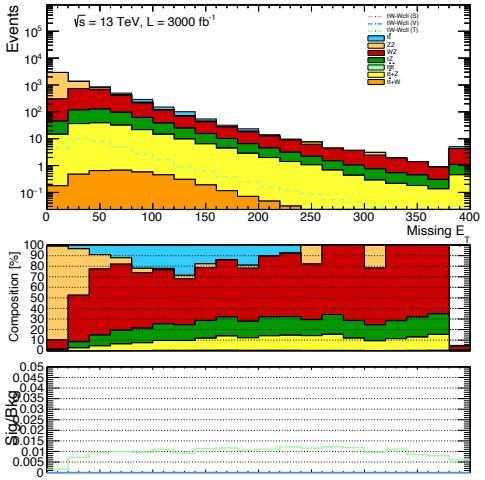


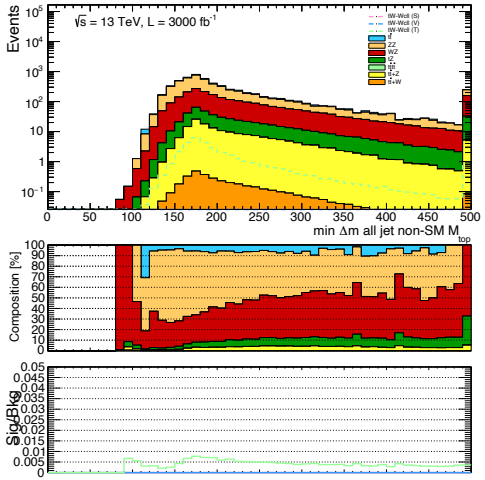


tW-charm couplings distributions

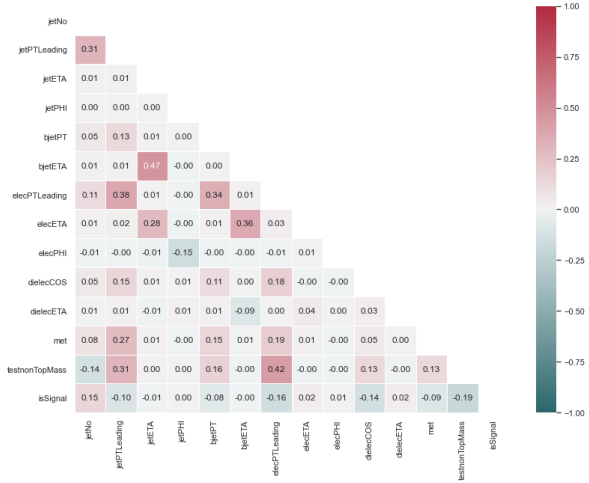




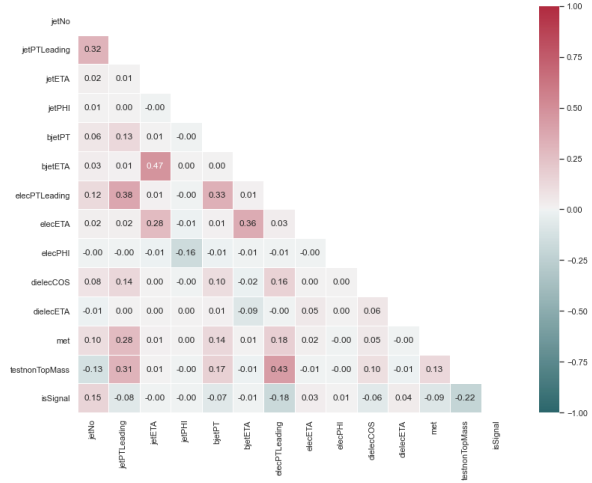




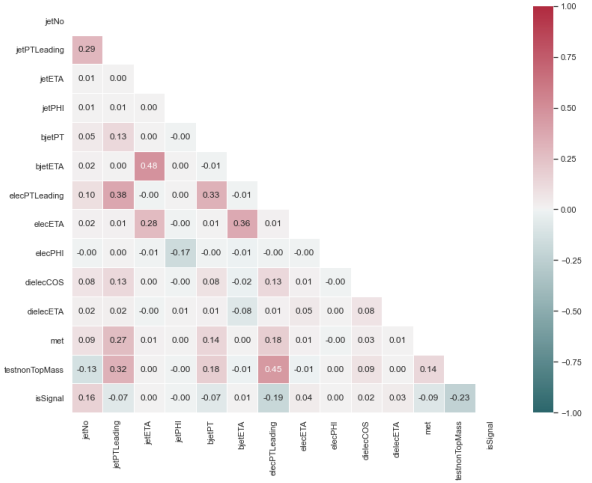
ttbar-charm correlations



Scalar coupling



Vector coupling

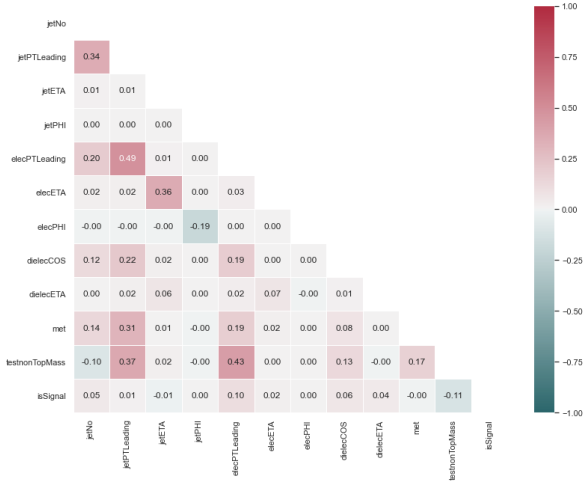


Tensor coupling

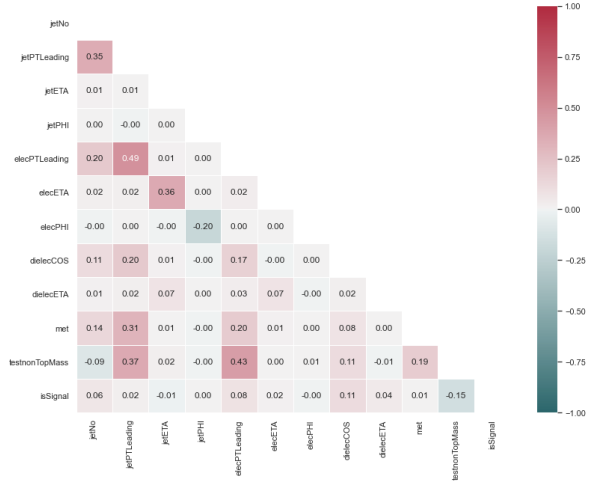
IsSignal is mostly (negatively) correlated to non-SM top mass
JetNo is (positively) correlated – means signal prones to more jets

tW-charm correlations

Scalar coupling



Vector coupling



Tensor coupling

IsSignal is mostly (negatively) correlated to non-SM top mass
JetNo is (positively) correlated – means signal prones to more jets

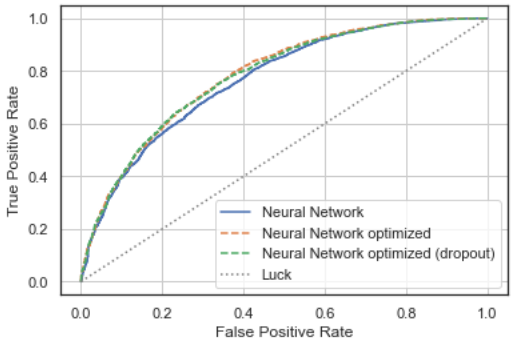
ttbar-charm ROC and AMS

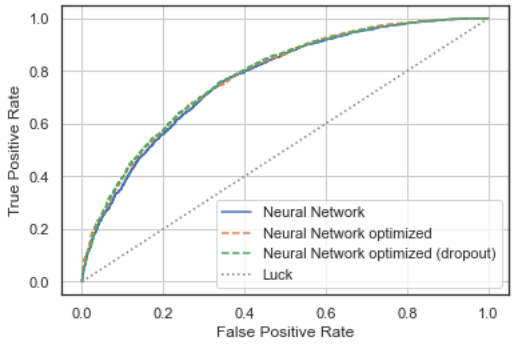
Scalar coupling

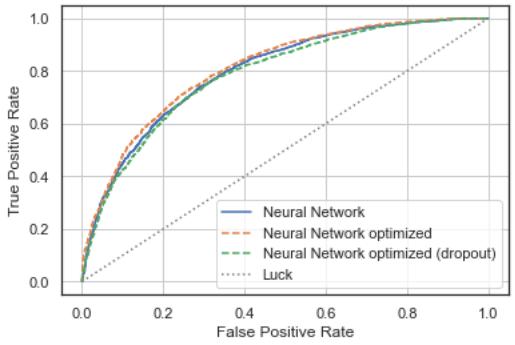
Vector coupling

Tensor coupling

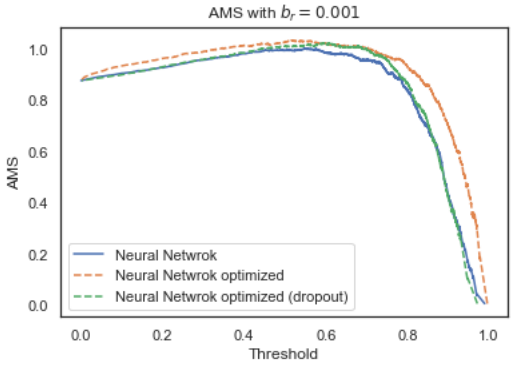
ROC

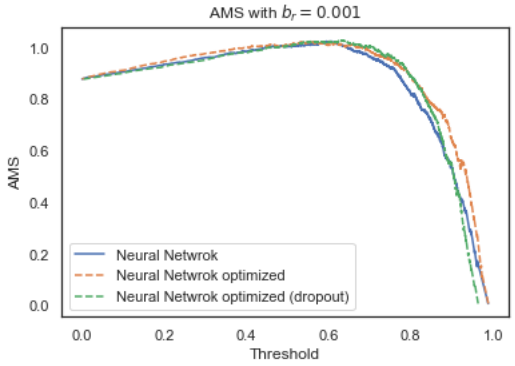


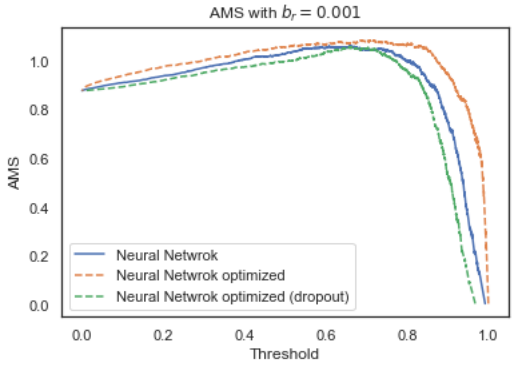




AMS







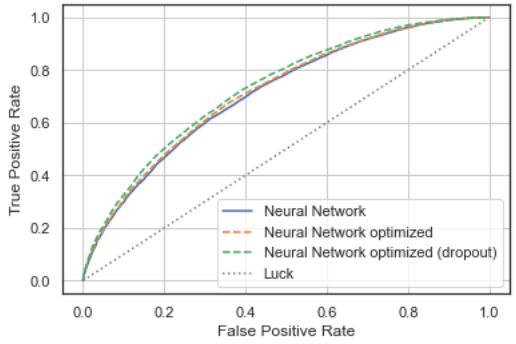
tW ROC and AMS

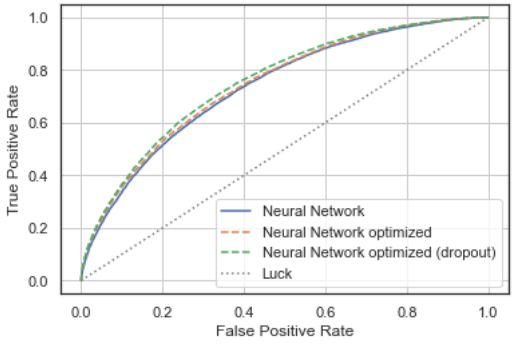
Scalar coupling

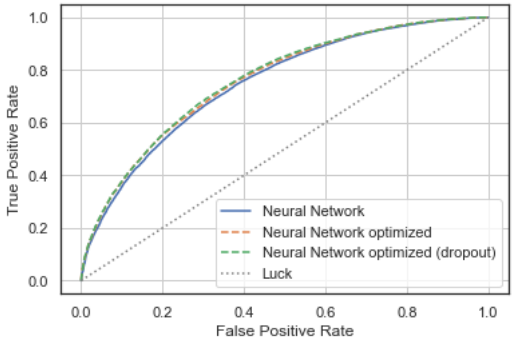
Vector coupling

Tensor coupling

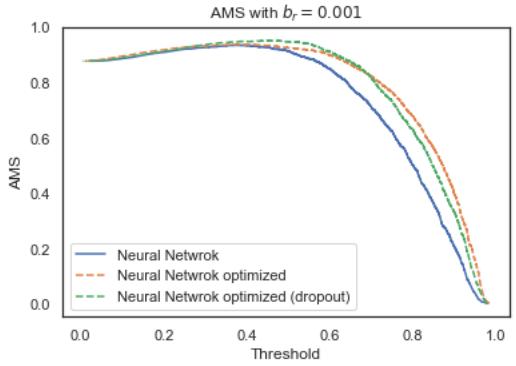
ROC

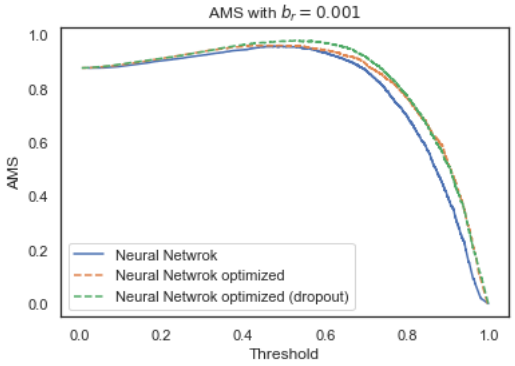


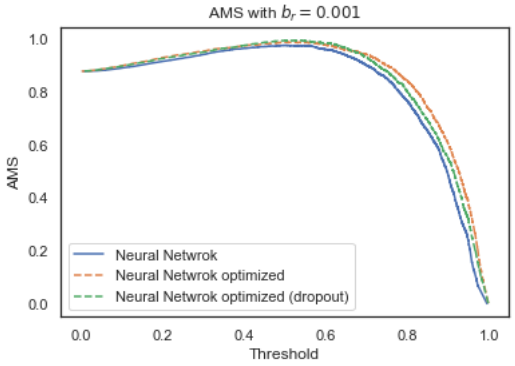




AMS







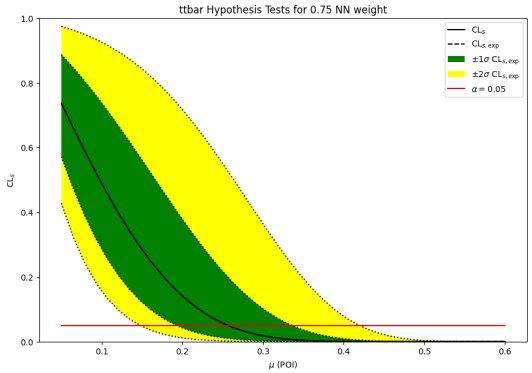
ttbar-charm upper limits on μ_{sig}

- To get upper limits, we just need to run multiple hypothesis tests for a lot of different null hypotheses of BSM with $\mu_{sig} \in [0,\ldots, 5.0]$ and then find the value of μ_{sig} for which the null hypothesis is rejected (a 95% CLs).

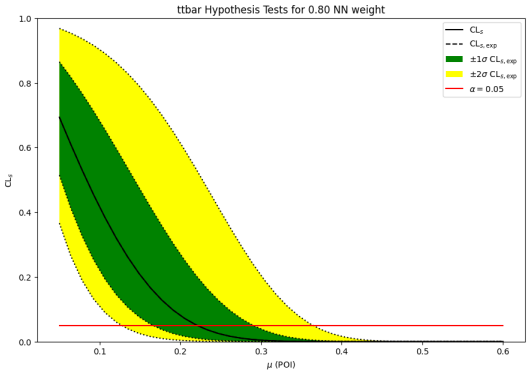
- We can plot the standard "Brazil band" of the observed and expected CLs. The horizontal red line indicates the test size ($\alpha = 0.05$), whose intersection with the CLs lines visually represents the (1–α)% CL limit on the μ_{sig}.

- Going to higher AMS threshold, signal background ratio gets bigger and then the 95% CL limit for μ_{sig} becomes smaller.

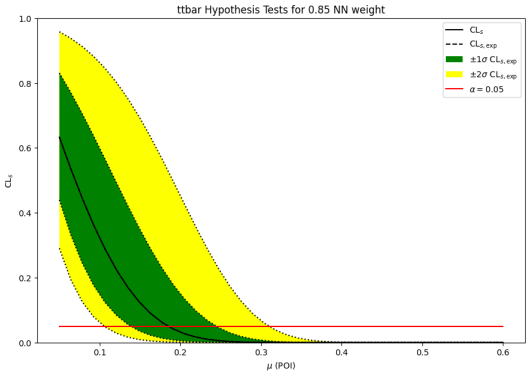
Upper limit (exp): μ = 0.256



Upper limit (exp): μ = 0.222

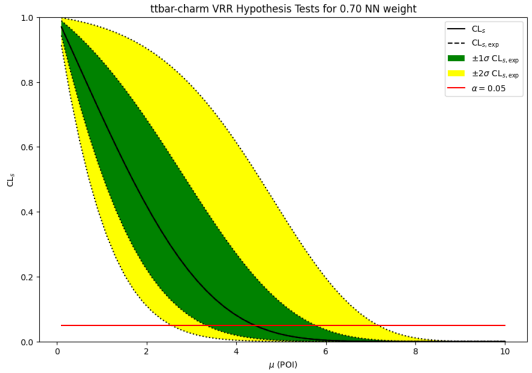


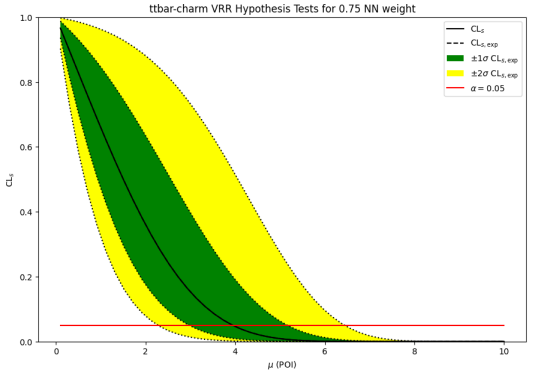
Upper limit (exp):μ = 0.186

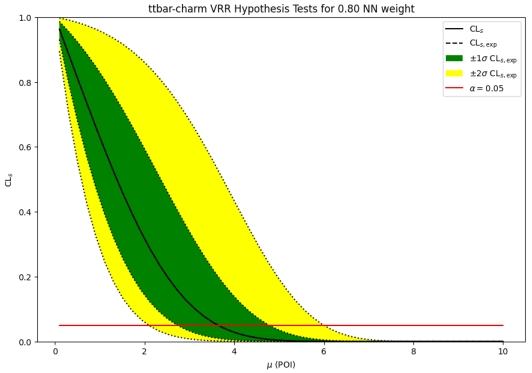


ttbar-charm couplings upper limits

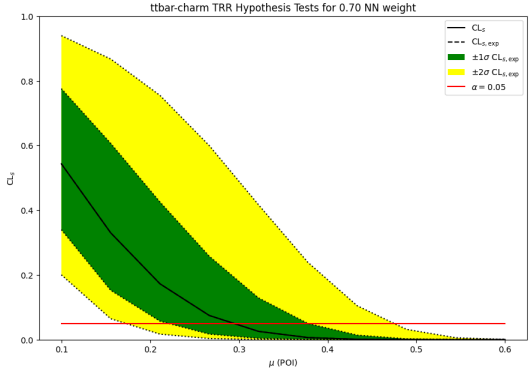
Vector like coupling

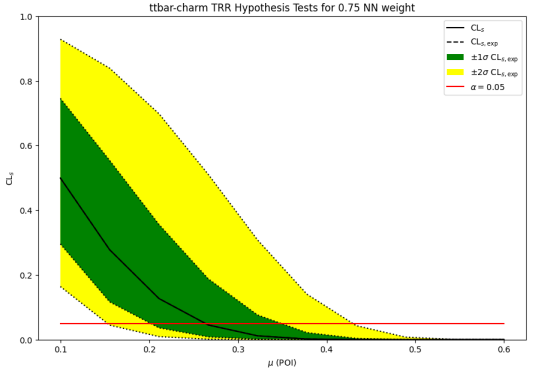


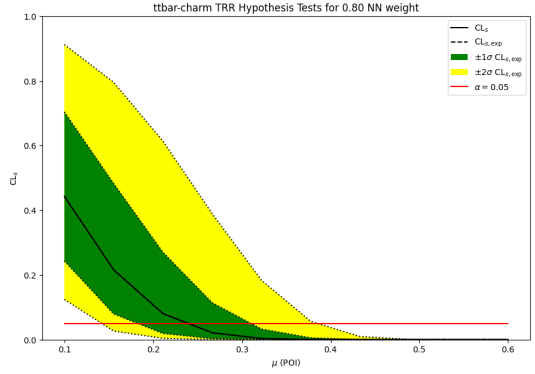




Tensor like coupling

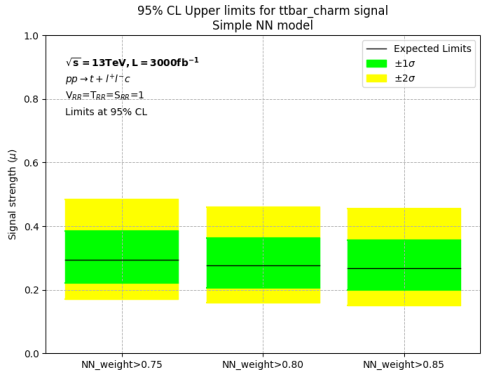




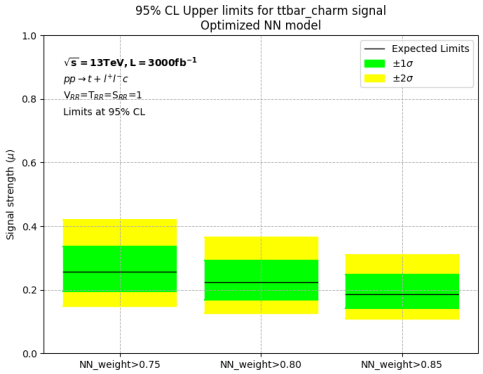


ttbar-charm upper limits on μ_{sig}

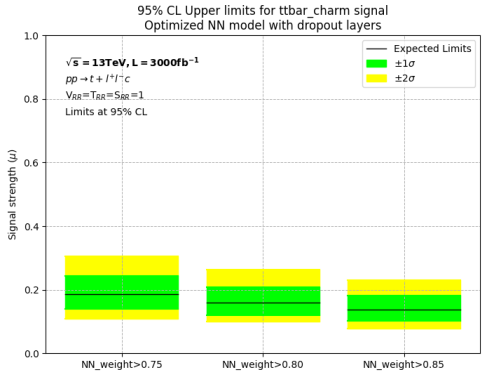
Simple NN



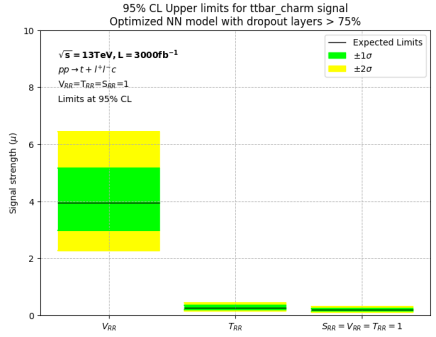
Optimized NN

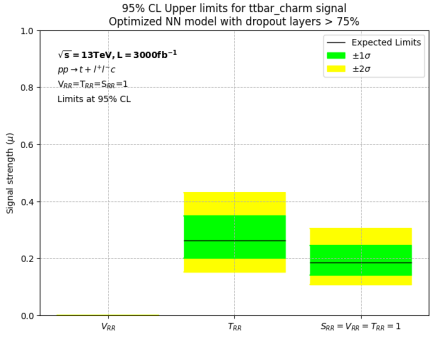


Optimized NN with drop out

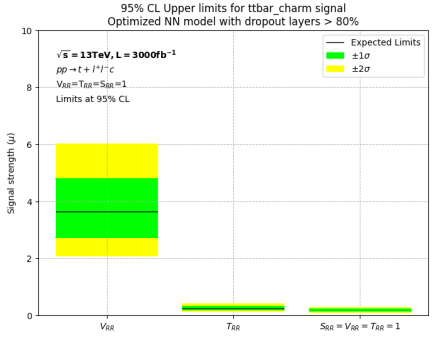


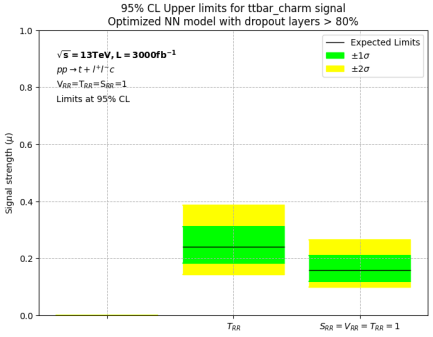
UL for different signal couplings (NN>75%)





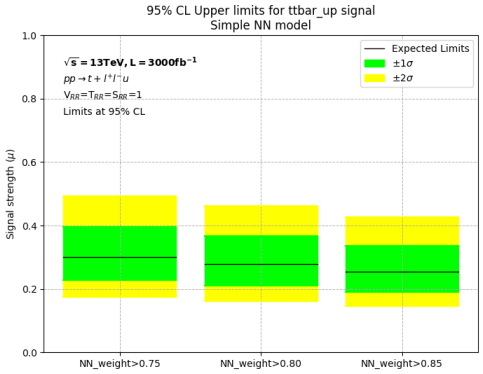
UL for different signal couplings (NN>80%)



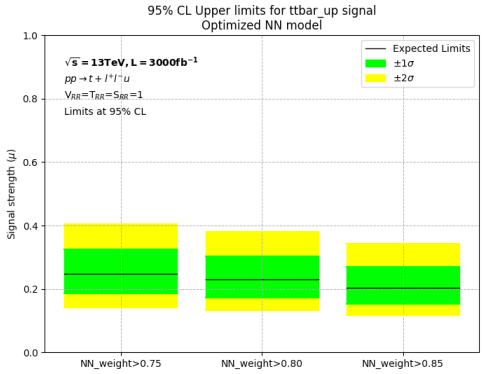


ttbar-up upper limits on μ_{sig}

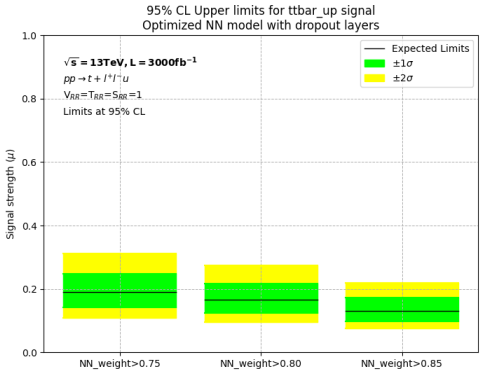
Simple NN



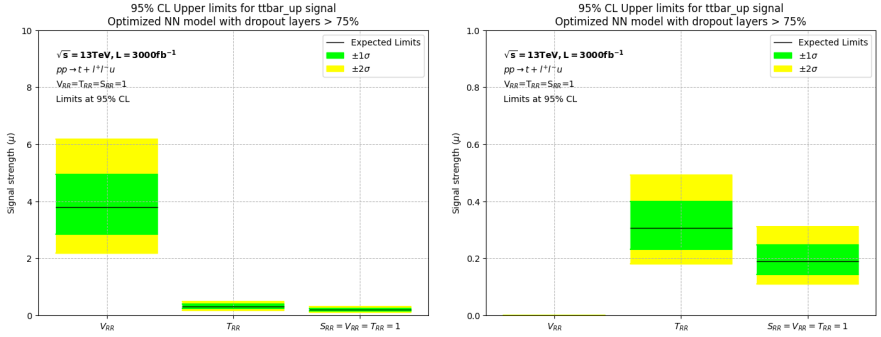
Optimized NN



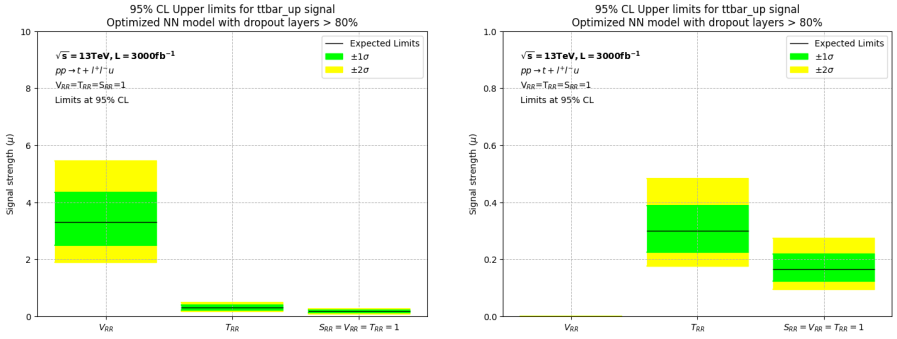
Optimized NN with drop out



UL for different signal couplings (NN>75%)



UL for different signal couplings (NN>80%)



Signal-background yields in ttbar-up

S=1

	0.75 NN cut	0.80 NN cut
signal	9.6	6.9
background	319.3	194.2
S/B	0.037	0.061

T=1

	0.75 NN cut	0.80 NN cut
signal	590.9	466.4
background	417.7	317.9
S/B	1.650	2.168

V=1

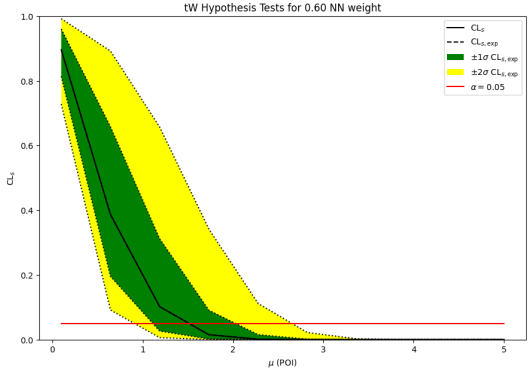
	0.75 NN cut	0.80 NN cut
signal	44.2	34.7
background	391.0	264.4
S/B	0.133	0.196

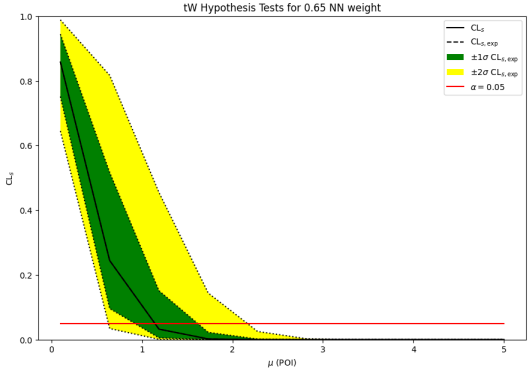
S=V=T=1

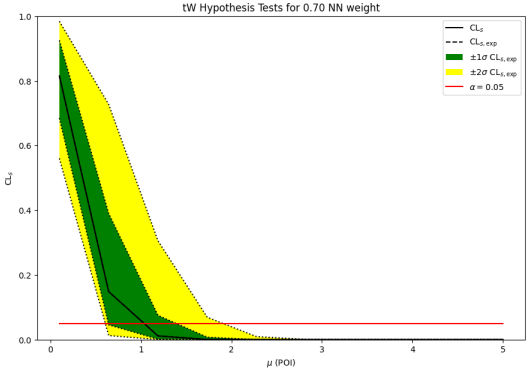
	0.75 NN cut	0.80 NN cut
signal	538.1	421.0
background	345.6	245.1
S/B	1.67	2.2

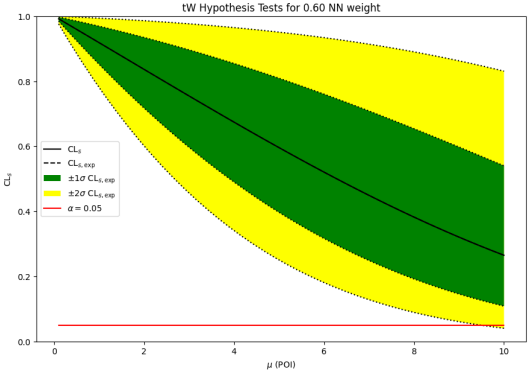
tW upper limits on μ_{sig}

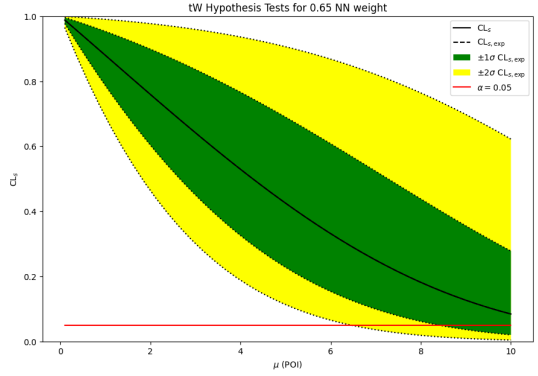
Typo error in the code

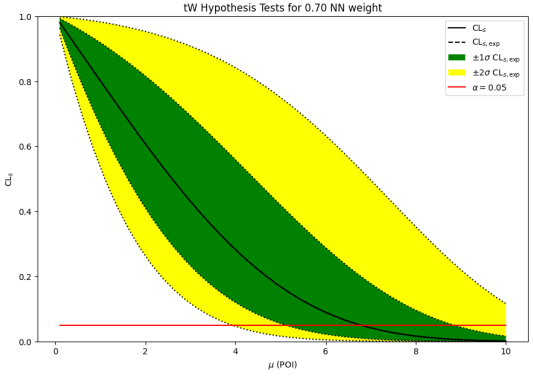












Signal-background yields in tW-charm

S=1

	0.75 NN cut	0.80 NN cut
signal	0.6	0.5
background	934.9	419.0
S/B	0.00081	0.00180

T=1

	0.75 NN cut	0.80 NN cut
signal	331.5	279.0
background	1393.0	686.4
S/B	0.271	0.549

V=1

	0.75 NN cut	0.80 NN cut
signal	3.2	2.7
background	1503.5	702.6
S/B	0.00244	0.00522

S=V=T=1

	0.75 NN cut	0.80 NN cut
signal	43.0	35.3
background	1143.7	565.1
S/B	0.044	0.089

Summary

- ttbar and tW signals with separate couplings has been studied and all variable distributions are made. For both channels, the non-SM top mass is the best discriminator.
- Several ML classifiers are trained using subset of data and important analysis features. NN gives higher accuracy score, TPR and lower FPR. NN models (simple and optimized) are applied to the whole dataset and the NN weights are saved in a separate tree.
- NN model does a great job in ttbar channels and the UL is almost less than 1. Because of low xsec for tW channels, NN shows weak performance in terms of UL. This mean analysis is not so sensitive to tW channels!
- Analysis tree production with important variables and plotting framework are done (tree production framework, plotter framework, ML weights, Statistical fits).
- As the next step, we can start writing 90% report including all the results. Starting point was the last year first of Mehr.
- Your feedback is welcome and appreciated.

Backup

Cross sections in pb

ttbar channels

```
# ttbar coupling channel info
sig_couplings = ['signal_charm_SRR', 'signal_charm_VRR', 'signal_charm_TRR', 'signal_up_SRR', 'signal_up_VRR', 'signal_up_TRR']
# cross-sections (pb)
xsec_sig_couplings = [0.0002, 0.0008, 0.0101, 0.0002, 0.0008, 0.0101]
# number of events generated
sig_event_couplings = [3*10**6, 3*10**6, 3*10**6, 3*10**6, 3*10**6, 3*10**6]

sig = ['signal_charm', 'signal_up']
# cross-sections (pb)
xsec_sig = [0.01376, 0.01376]
# number of events generated
sig_event = [3*10**6, 3*10**6]
```

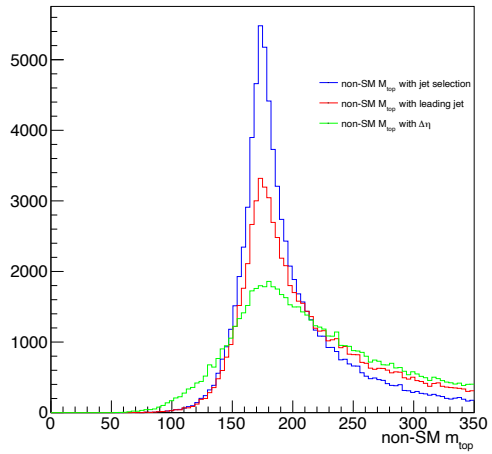
tW channels

```
# tW coupling channel info
sig_tW_couplings = ['signal_tW_charm_SRR', 'signal_tW_charm_VRR', 'signal_tW_charm_TRR', 'signal_tW_up_SRR', 'signal_tW_up_VRR', 'signal_tW_up_TRR']
# cross-sections (pb)
xsec_sig_tW_couplings = [0.000012, 0.000048, 0.0005, 0.000012, 0.000048, 0.00051]
# number of events generated
sig_event_tW_couplings = [3*10**6, 3*10**6, 3*10**6, 2*10**6, 2*10**6, 2*10**6]

sig_tW = ['signal_tW_charm', 'signal_tW_up']
# cross-sections (pb)
xsec_sig_tW = [0.0007, 0.0007]
# number of events generated
sig_event_tW = [3*10**6, 3*10**6]
```

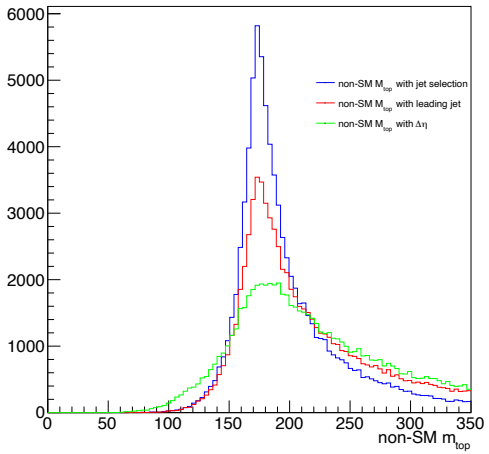
tW channel non-SM top mass reconstruction

- Three algorithms used to reconstruct non-SM top mass:
  1. the min $\Delta\eta$ between electrons is used to select OP electrons and subsequently non-SM top mass reconstruction (green)
  2. the leading non-btagged jet and the 3 electrons are the inputs for $\min(|m_{llq} - m_{top}|)$ to choose the best selection for OS electrons (red)
  3. Loop over all the electrons and jets to get $\min(|m_{llq} - m_{top}|)$. The combination will be used to indicate OS leptons (blue)

Signal charm



Signal up



Signal and background generation

- Signal and background events are generated with MG5 (for ME) + PYTHIA (for PS and HAD) + Delphes (for HLLHC CMS card detection). almost 3M events for both charm and up signals and 2M events for each background.

- Weights look fine (<1) for all signal and background events. Extra 15M $t\bar{t}$ events are being generated to have better ML training (the third lepton in $t\bar{t}$ should be fake btw).

- Here is the weight summary for all analysis processes:

  weights = {'ttbarZ': 0.00431, 'tZ': 0.00375, 'tttt': 2.79520e-05, 'ZZ': 0.67125, 'ttbar': 0.9485, 'ttbarW': 0.00015, 'WZ': 0.13575,'signal_charm': 0.01376, 'signal_up': 0.01376}

- The preselections applied:
  1. exactly 3 leptons (for now just electrons) with one pair of OS
  2. at least 2-jets with one b-tagged jet
  3. minimum P_T cut and η cut to pass di-lepton trigger

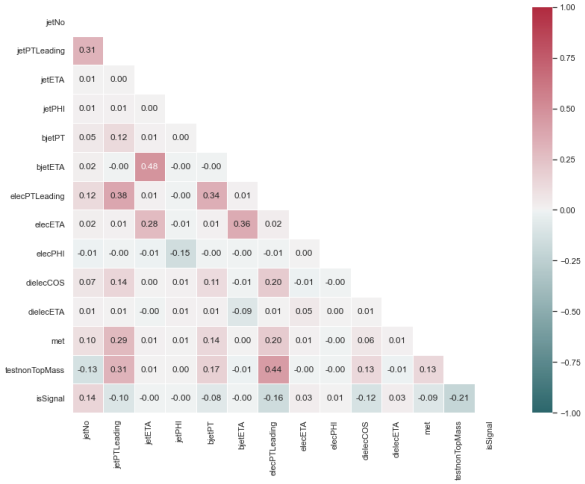
Simple NN structure

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input (InputLayer)          [(None, 13)]              0

 hidden1 (Dense)             (None, 20)                280

 hidden2 (Dense)             (None, 20)                420

 output (Dense)              (None, 1)                 21

=================================================================
Total params: 721
Trainable params: 721
Non-trainable params: 0
```

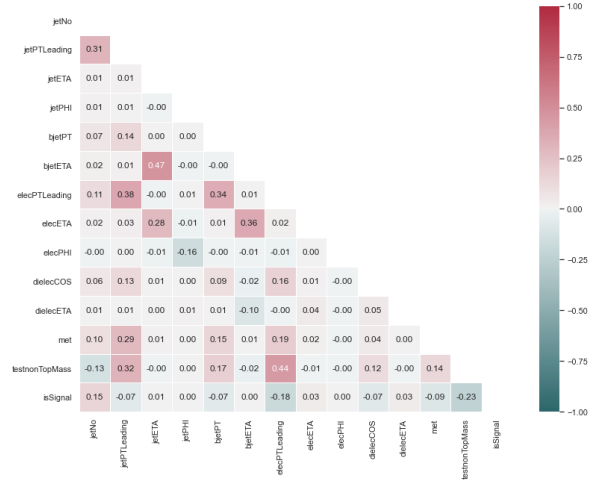
Keras-tuner to tune NN Hyperparameters

```
RandomizedSearchCV(cv=5,
                   estimator=Pipeline(steps=[('scaler', StandardScaler()),
                                             ('clf',
                                              <keras.wrappers.scikit_learn.KerasClassifier object at 0x7fe642490880>)]),
                   n_iter=5,
                   param_distributions={'clf__activation': ['selu', 'relu',
                                                            'tanh'],
                                        'clf__batch_size': [64, 128, 256, 512],
                                        'clf__dropout_rate': [0.1, 0.01],
                                        'clf__epochs': [5, 10, 15, 50, 100,
                                                        200],
                                        'clf__k_initializer': ['lecun_normal',
                                                               'normal'],
                                        'clf__network_layers': [(32, 32),
                                                                (64, 64),
                                                                (128, 128,
                                                                 128)],
                                        'clf__optimizer': ['Nadam', 'Adam',
                                                           'SGD'],
                                        'clf__verbose': [0]},
                   scoring='accuracy')
```

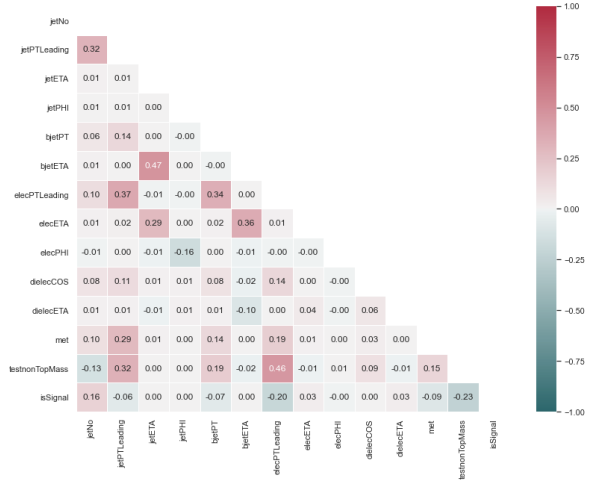
ttbar-up correlations



Scalar coupling



Vector coupling



Tensor coupling

IsSignal is mostly (negatively) correlated to non-SM top mass
JetNo is (positively) correlated – means signal prones to more jets

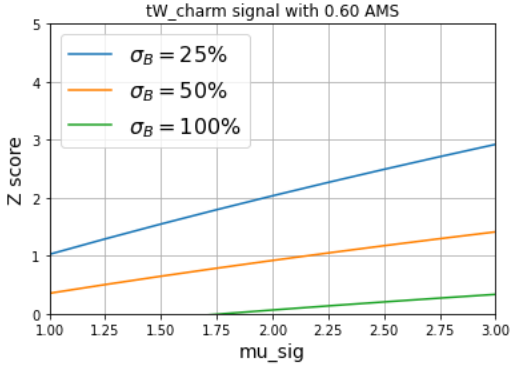
tW significance and p-value

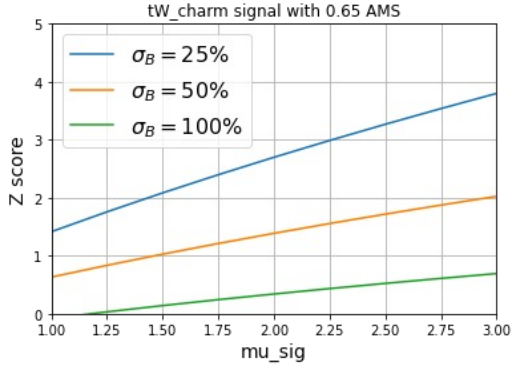
Significance → $p(N_s, N_b, \sigma_b) = \mathcal{I}\left(\frac{1}{1+\frac{1}{N_b\sigma_b^2}}; N_s + N_b; \frac{1}{\sigma_b^2}+1\right)$

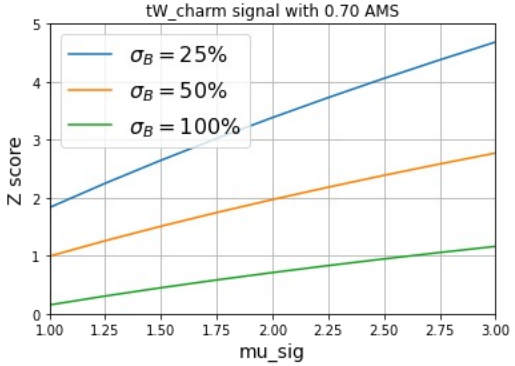
Simple NN

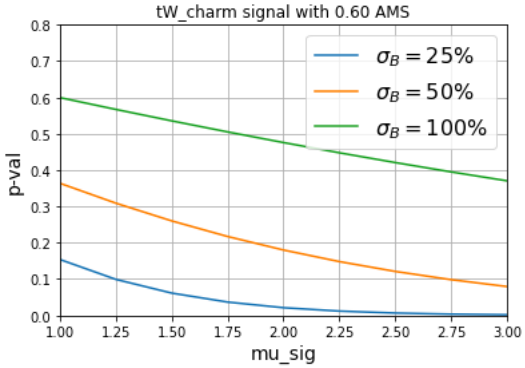
Optimized NN

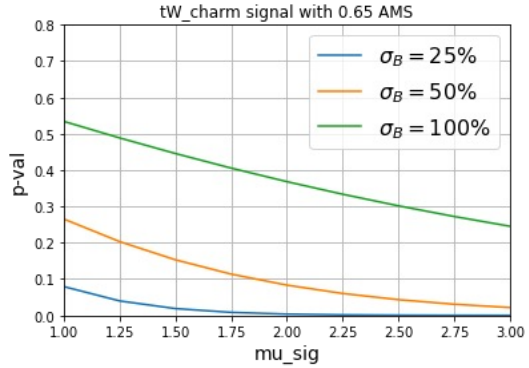
Optimized NN with drop out layers

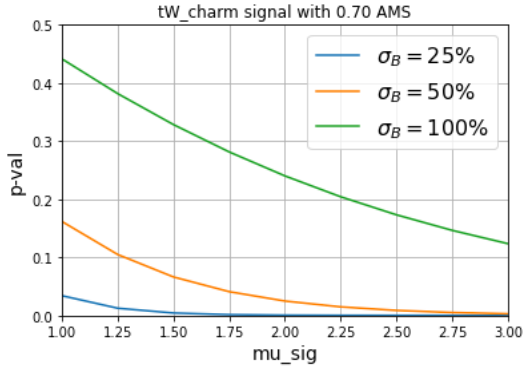






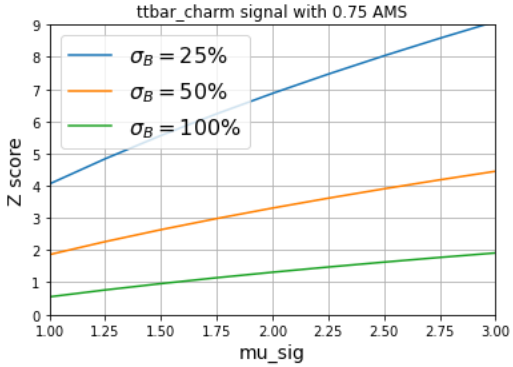


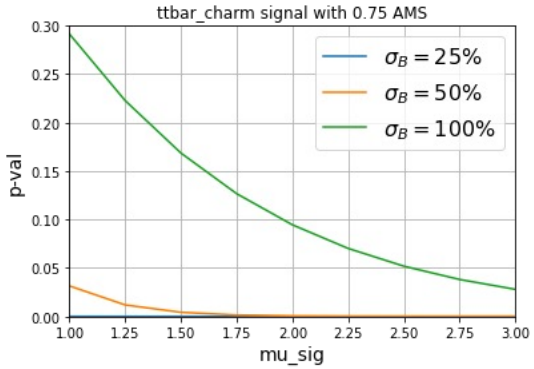




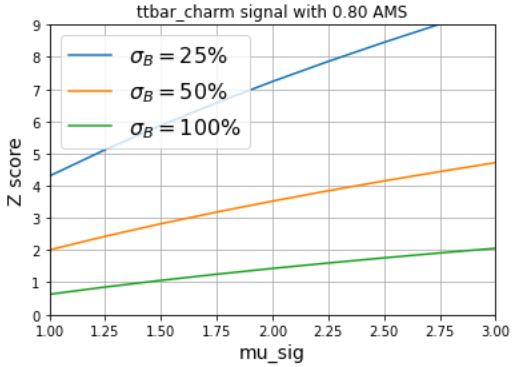
ttbar significance and p-value

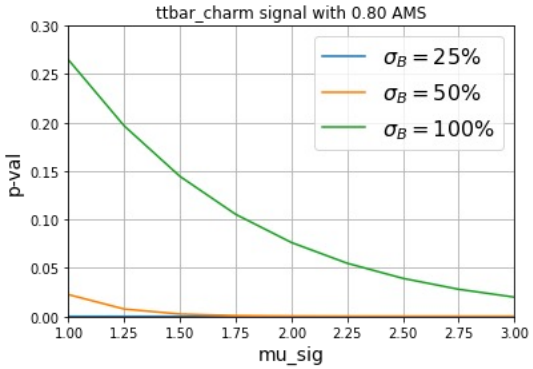
Simple NN





Optimized NN





Optimized NN with drop out layers