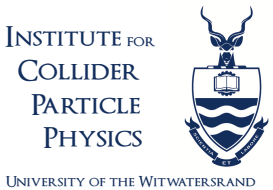
Two same sign and three leptons final states in four top-quark production at the LHC

Thuso Mathaha, Mukesh Kumar, Bruce Mellado

Kruger 2022: Discovery Physics at the LHC

University of the Witwatersrand
School of Physics
Institute for Collider Particle Physics

4-9 December 2022



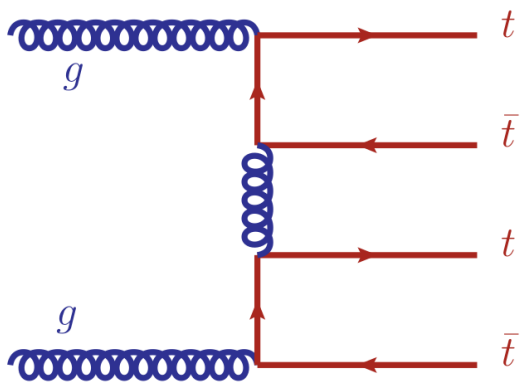
Overview

- Introduction
- Production of four tops
- Analysis:
  - 2SSℓ and 3ℓ category
  - Discrimination of signal from background
  - Kinematic variables
  - DNN classifier
- Summary

Introduction: multi-leptons anomalies

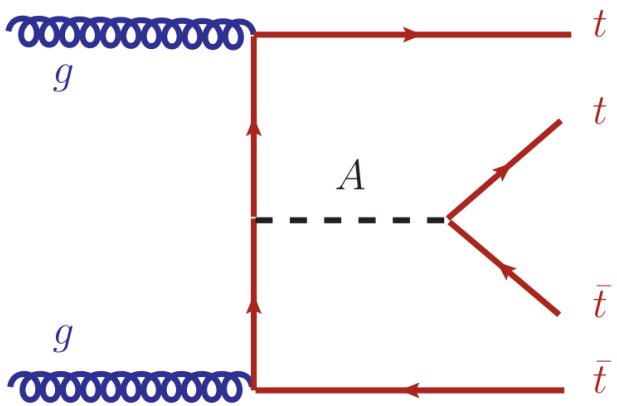
- Anomalies in multi-lepton final states through Higgs boson were reported in 1901.05300.
- To explain these anomalies a 2HDM+S model was introduced where the decay chain $H \to Sh, SS$.
- To further explore results with more data and new final states, the parameters of the model were fixed in 2017 according to 1711.07874.
- This includes setting the scalar masses to $m_H = 270\,\text{GeV}$, $m_S = 150\,\text{GeV}$, treating S as a SM Higgs-like scalar and assuming the dominance of the decays $H \to Sh, SS$.
- Given the success of a 2HDM+S model to describe the excess mentioned above with the production of H and S, is it reasonable to wonder if there are emerging signs in the data of the pseudoscalar A?

Production of four tops



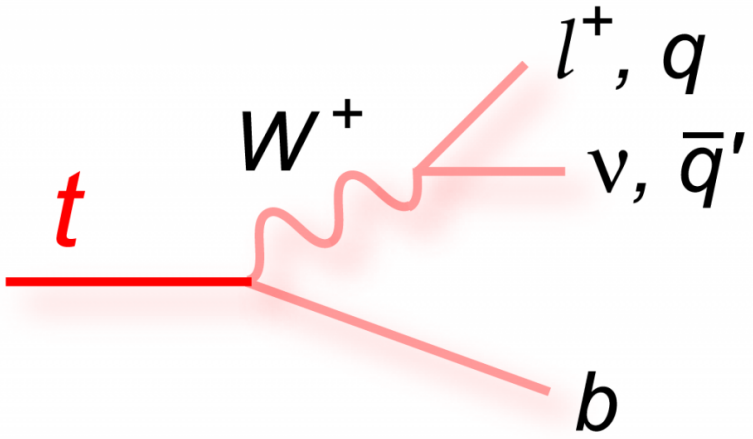
- The production of four top-quark is one of the relevant rare processes predicted by the SM and recently been observed by the ATLAS (2007.14858, 2106.11683) and CMS (1908.06463) collaborations.
- The CMS measurement is consistent with the SM, while ATLAS measurements are systematically above the the SM.
- The cross section of 4tops in the SM is very low.
- The predicted cross section by SM $\sigma_{t\bar{t}t\bar{t}} = 12.0 \pm 2.4\,\text{fb}$.

Production of four tops



- Many Beyond the SM (BSM) scenarios are expected to provide enhancement of this cross-section.
- One of BSM scenarios is the production of a heavy pseudoscalar (A) in association with a top quark pair ($t\bar{t}$) in the extended two-Higgs-doublet model with a singlet scalar 2HDM+S.
- We consider the associated production $t\bar{t}A$, with $A \to t\bar{t}$, leading to four tops in the final state.
- The model parameters are still fixed according to 1711.07874.

Analysis: 2SSℓ and 3ℓ category



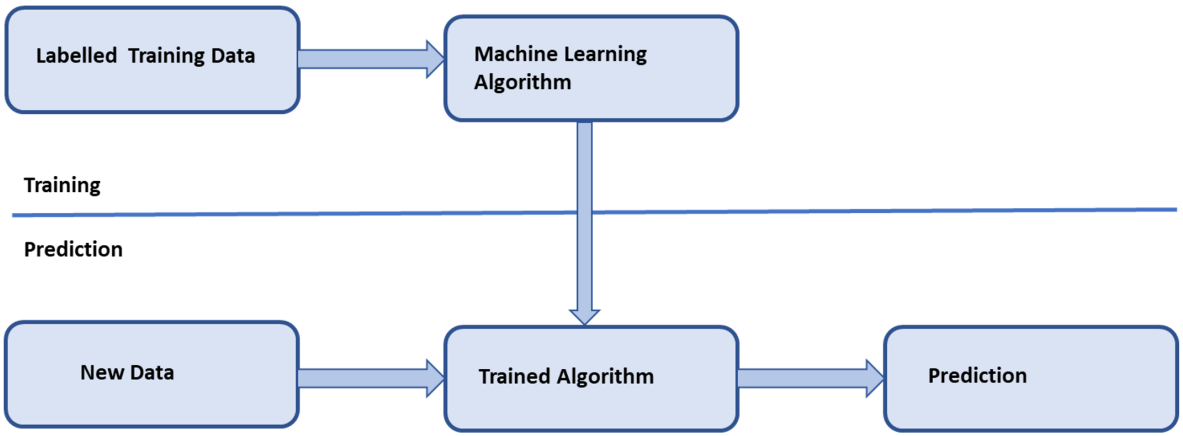
- The top quark decays into a W boson and a b-quark with a branching ratio of about 100%.
- Channels are split according to:
  - exactly two isolated leptons with the same electric charge (2SSℓ)
  - at least three isolated leptons (3ℓ)

Analysis: 2SSℓ and 3ℓ category

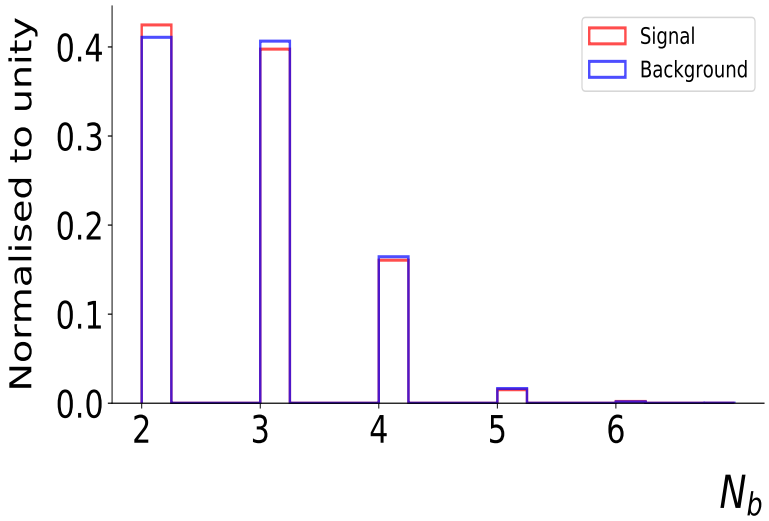
- Selection requirements:
  - 2 same-sign leptons(2SSℓ) or 3 leptons(3ℓ) ($\ell = e\mu$)
  - $\geq$ 6 jets with $p_T > 25$ GeV
  - $\geq$ 2 b-tagged jets
  - $H_T > 500$ GeV
- $H_T = \sum^{Leptons} p_T + \sum^{Jets} p_T$
- We evaluate the heavy pseudoscalar A with three different masses, $m_A = 400, 500, 600$ GeV.

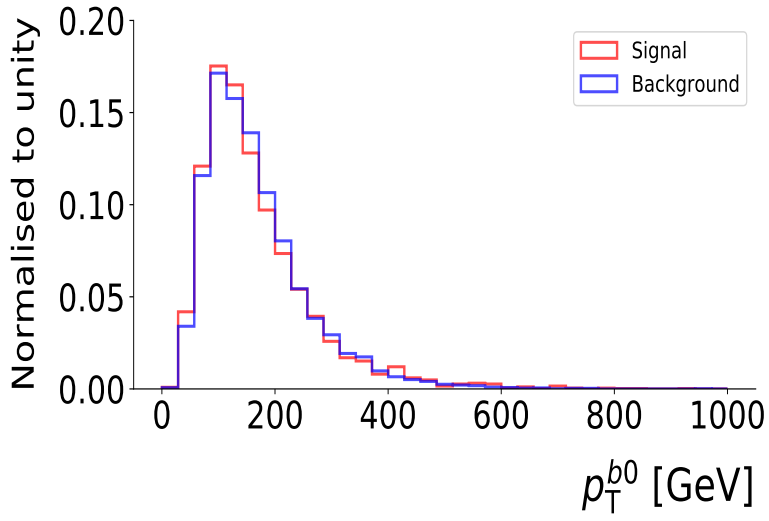
Discrimination of signal from background

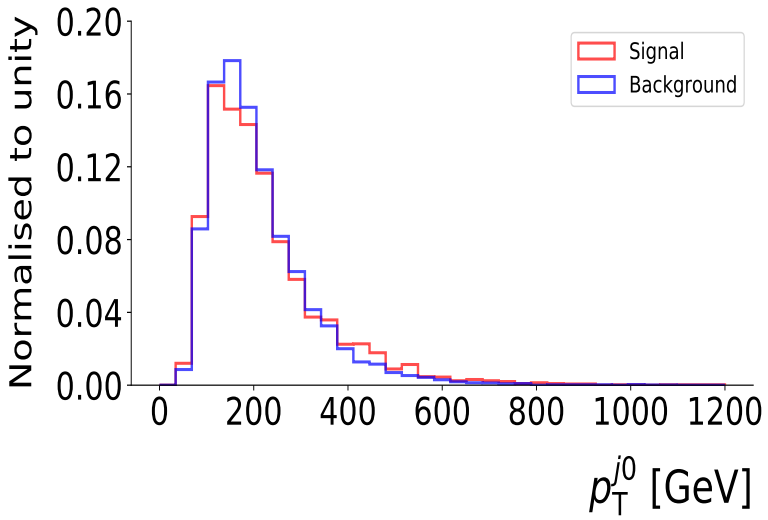
- The background composition of 2SSℓ and 3ℓ is largely dominated by the production of $t\bar{t}$ in association with additional jets.
- To separate signal from the background events, a multivariate discriminant is built by combining several kinematic observables in DNN.
- The DNN used in this study is a supervised learning algorithm, where it classifies signal from background.

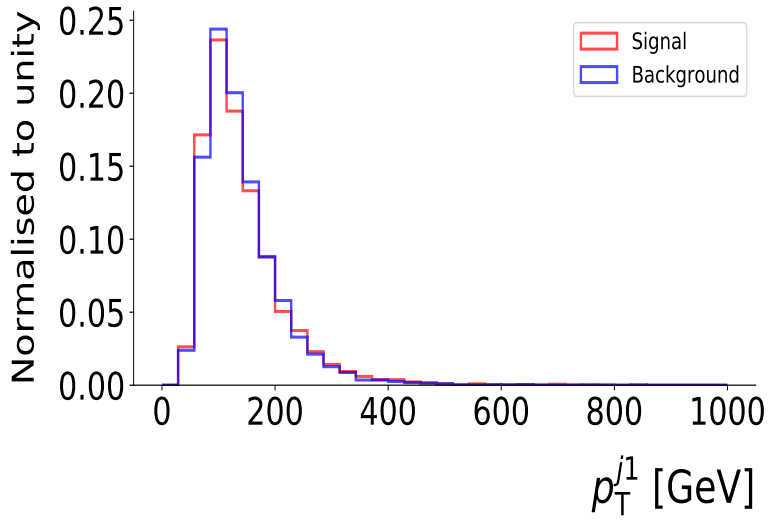


Kinematic observables



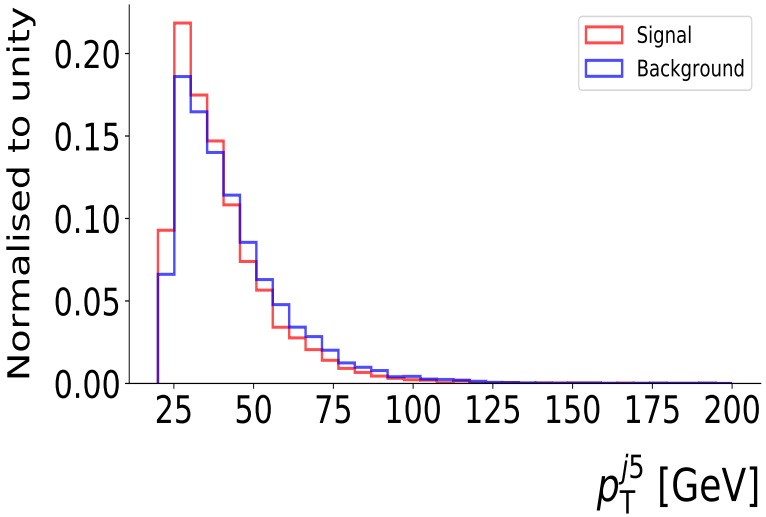


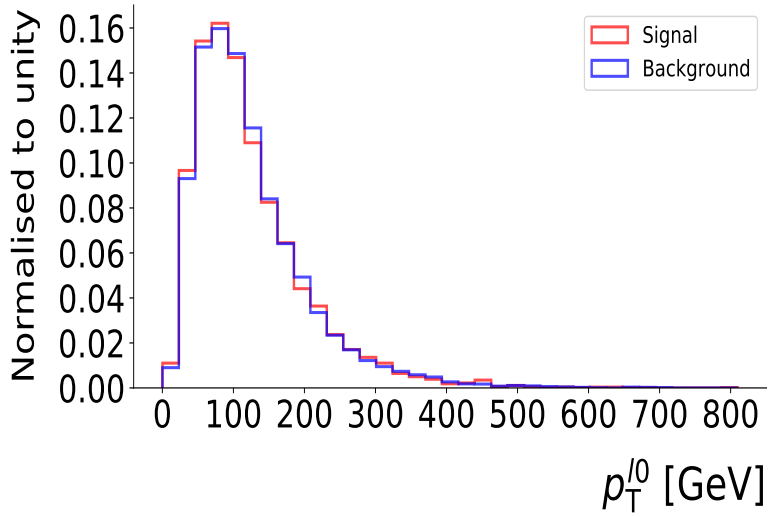


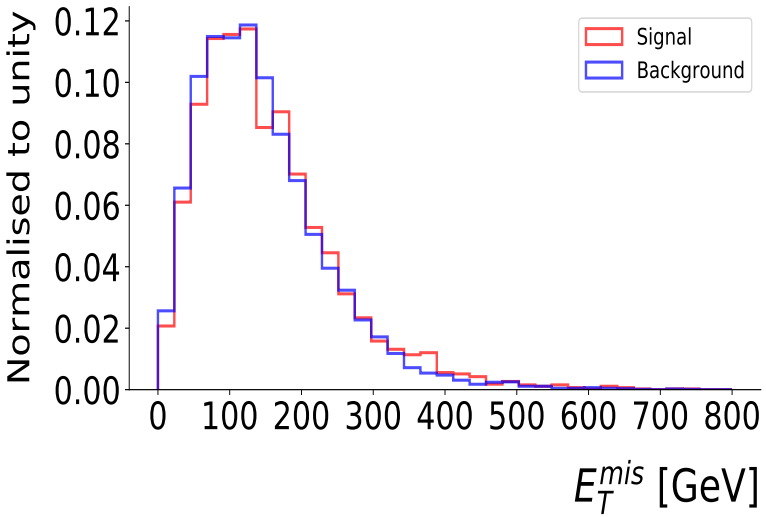


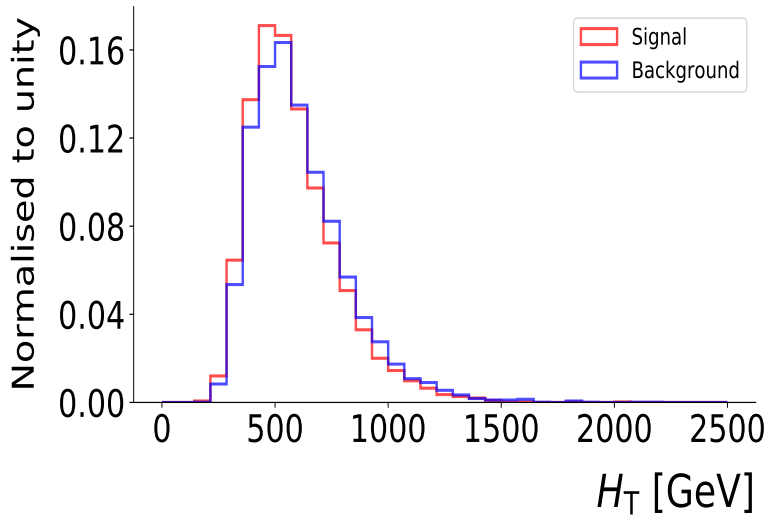
- Distributions of number of b-tagged jets, first leading b-tagged jet p_T, first and seconding leading jet p_T for signal and background.

Kinematic observables



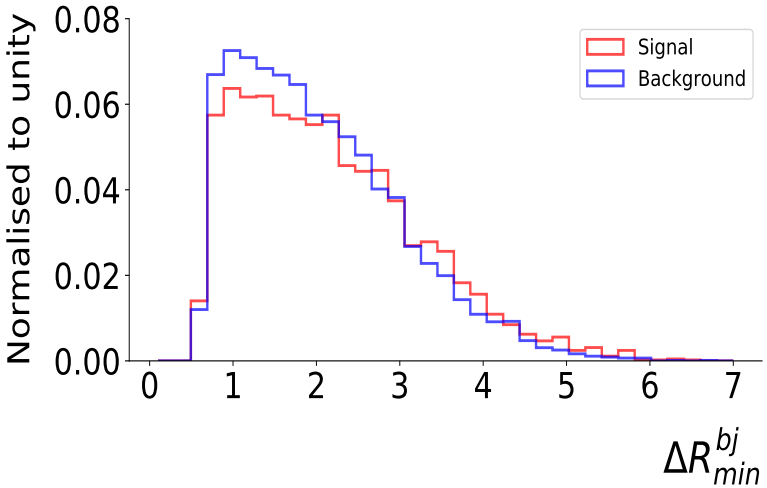


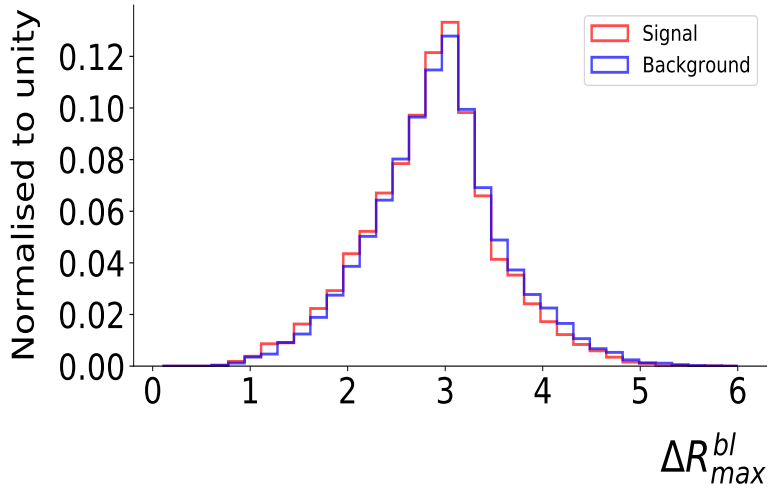


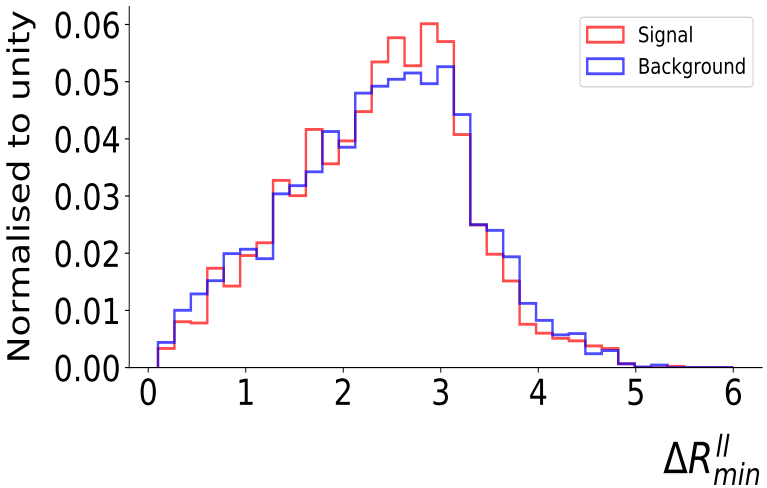


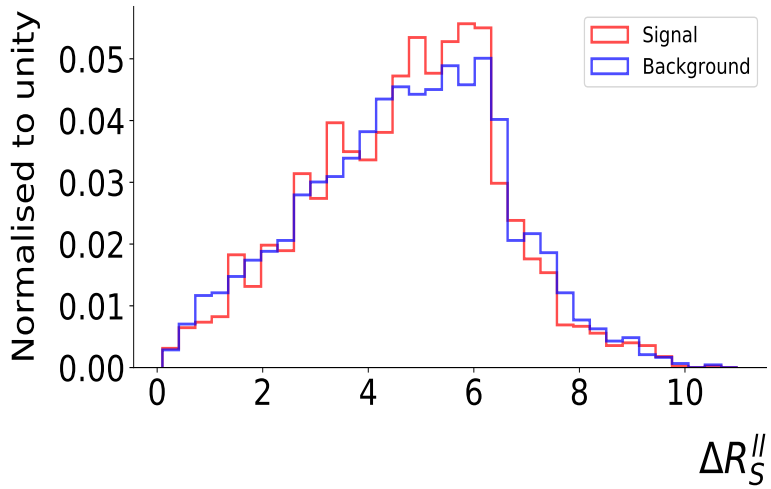
- Distributions of sixth leading b-tagged jet p_T, leading lepton p_T, missing transverse energy and the scalar sum of leptons and jets p_T.

Kinematic observables



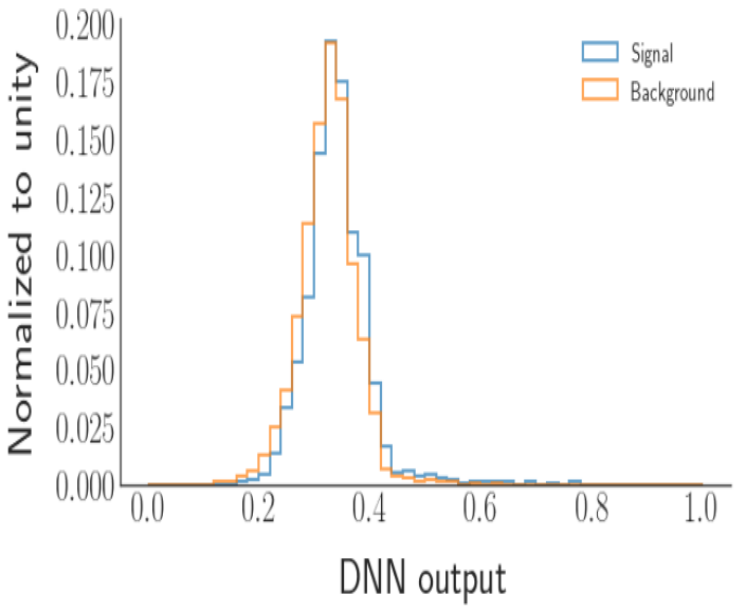


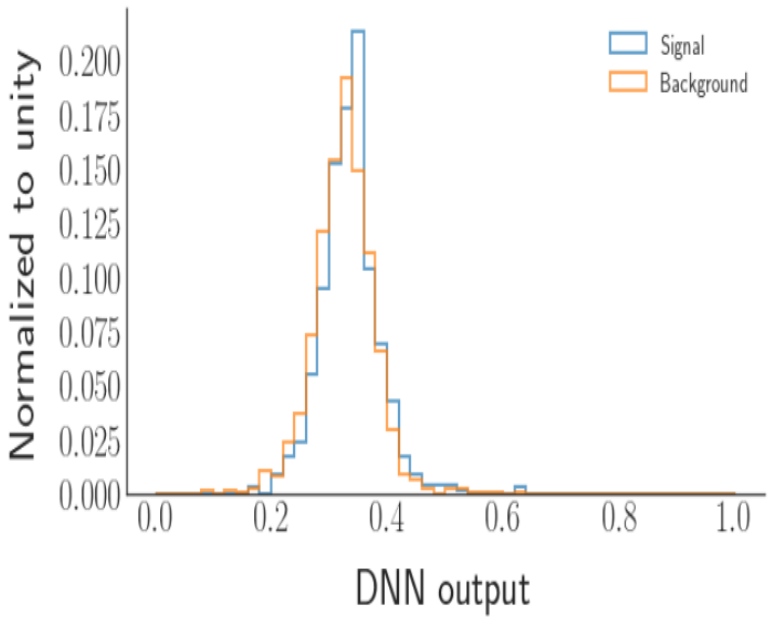




- The minimum distance between a b-tagged jet and jet, maximum distance between b-jet and lepton, the minimum distance between two leptons and the sum of distances between leptons.

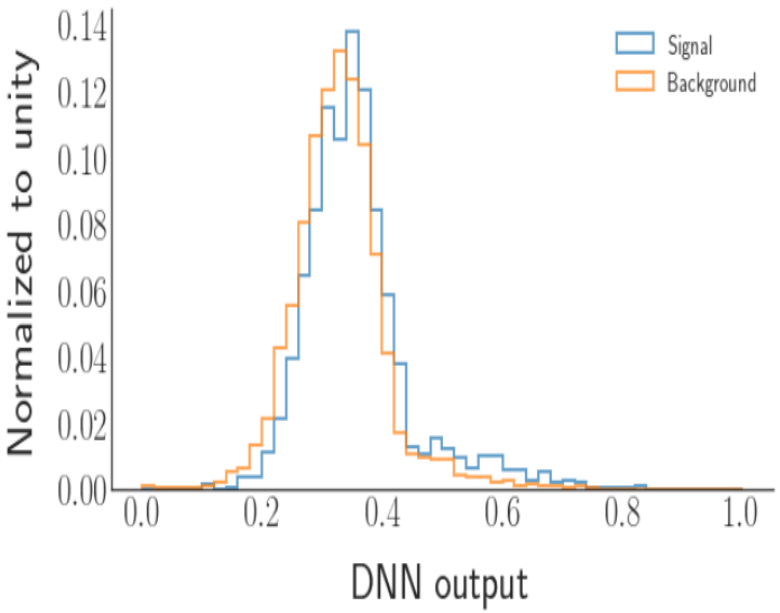
Deep Neural Network response: 2SSℓ

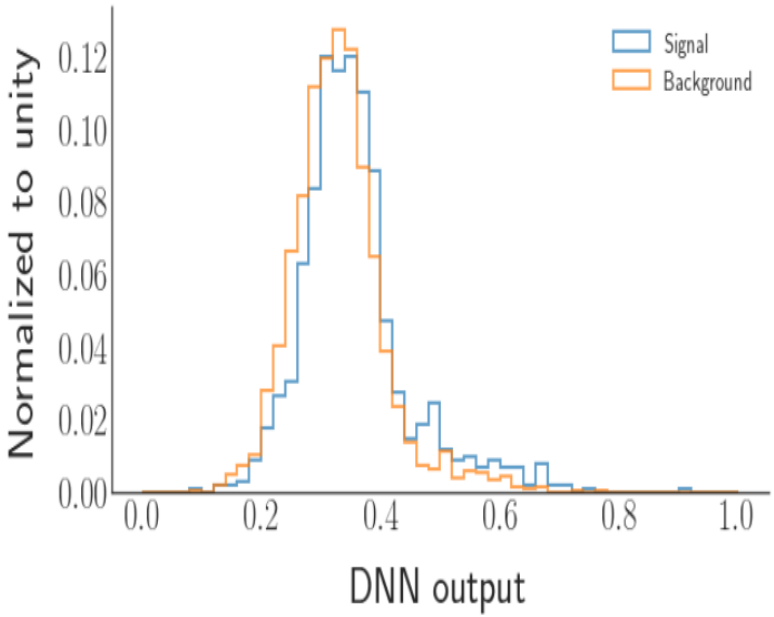




- Distributions of the DNN training (left) and testing (right) data for two same sign leptons category.

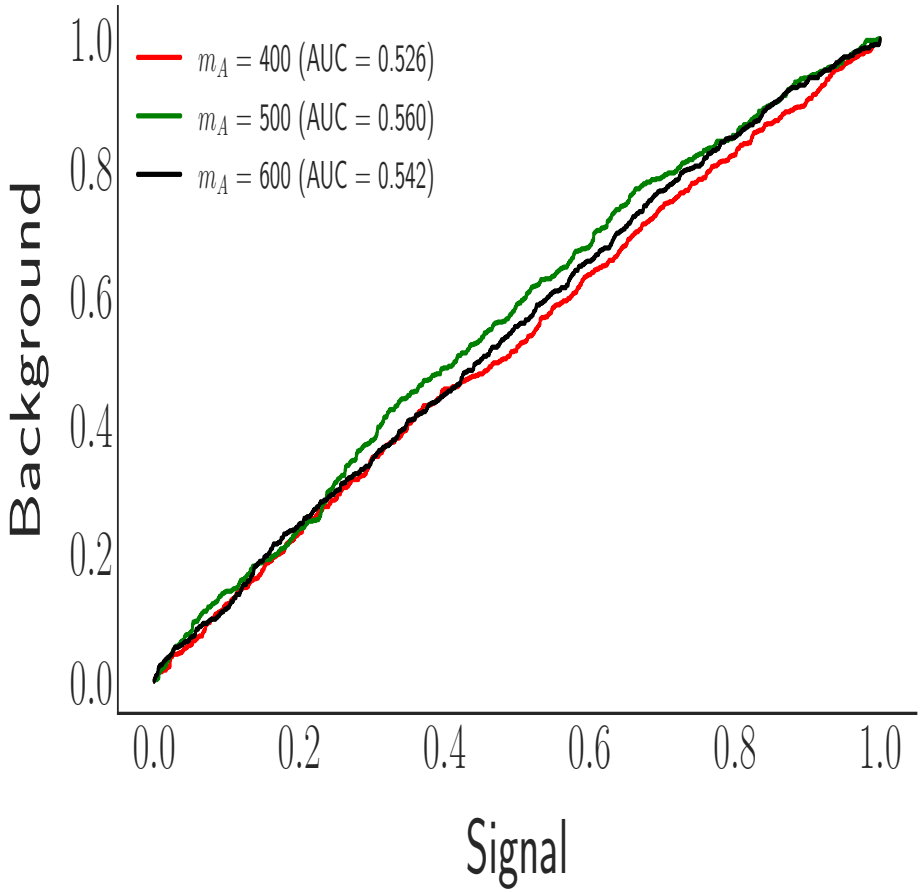
Deep Neural Network response: 3 Leptons

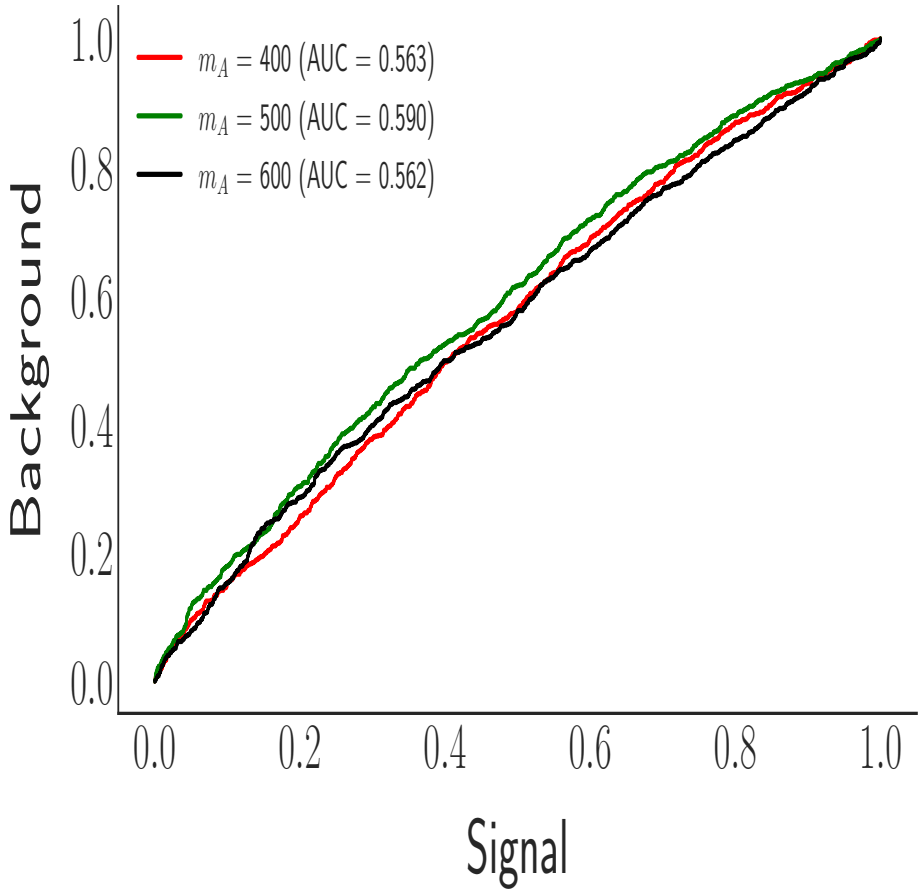




- Distributions of the DNN training (left) and testing (right) data for three isolated leptons category.

Receiver Operating Characteristic curve





- Roc curves for both categories, 2SSℓ (left panel) and for 3ℓ (right panel).

Summary

- We have studied the production of the four top-quark production at the center of mass $\sqrt{s} = 13\,\text{TeV}$ at the LHC using two categories of multi-lepton channels: two same-sign leptons and three isolated leptons.
- We observed that there is not much discrimination between the four top-quark production in the SM to that of BSM model used here.
- A multivariate analysis is performed with a DNN using twelve input features, where no discrimination between the SM and BSM four top-quark signals.
- This is illustrated by the AUCs of the ROC curves being marginally higher than 50%.
- In this way we constraint the involved parameters of 2HDM+S model and explain the observed data from experiments.

Thank you for your attention!