# Machine learning techniques for top-top event search with the ATLAS experiment at the LHC

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29 March 2023

# Introduction

It was analyzed the production process of **quark top *same-sign*** following proton-proton collisions taking place in the Large Hadron Collider at CERN in Ginevra using data collected by the ATLAS detector.

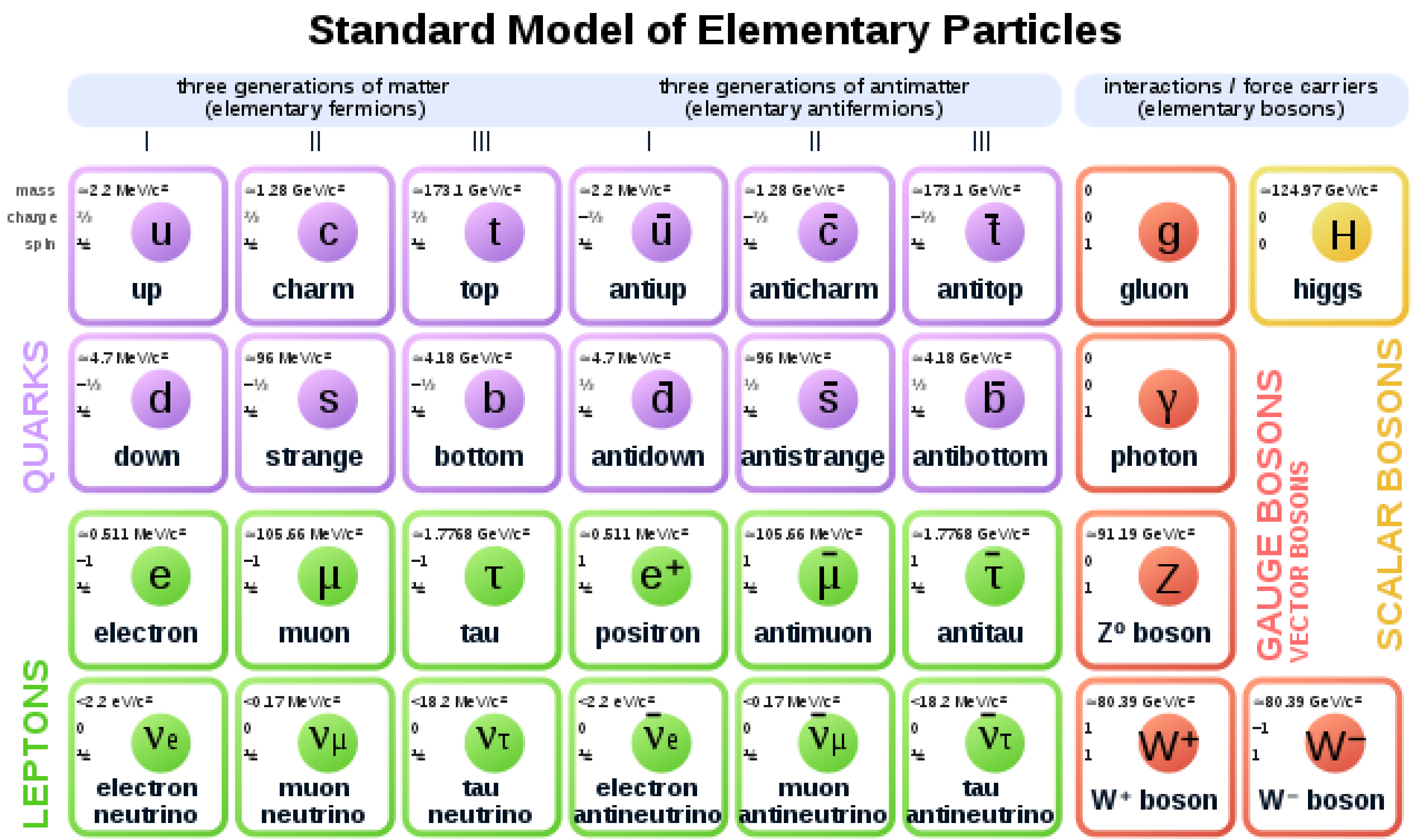
- Process strongly suppressed by the Standard Model → **BSM physics** research
- Analysis conducted with an **EFT-type approach**
- The thesis work is part of an ongoing analysis, using an alternative approach for signal/background discrimination

Three sets of variables of different **reconstruction levels** were chosen to be presented to a **neural network** optimized for signal-from-background discrimination to verify its performance.

# Standard Model (SM)

It describes almost all experimental observations:

- Twelve **FUNDAMENTAL PARTICLES** divided into **bosons and fermions**
- Three of the four **FUNDAMENTAL FORCES** present in nature (quantized field theories): **electromagnetic, weak and strong** (NO gravity)
- It leaves open some question marks, both on the experimental and theoretical side



# Effective Field Theories (EFT) and SMEFT

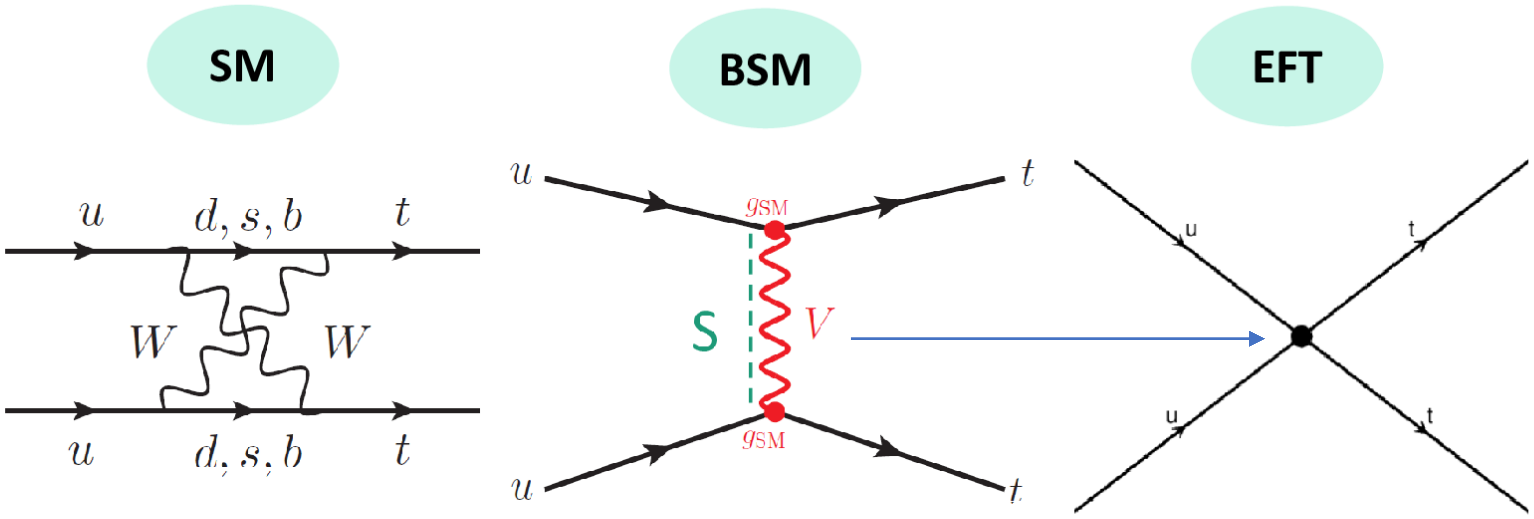
## Effective Field Theories (EFT)

- Approach to investigate «physics beyond the Standard Model», which applies to an already existing and verified model
- Understand the behavior of a theory at lower energies and then derive what is assumed to be a simpler model at higher energies

## SMEFT

$$\mathcal{L}_{TOT} = \mathcal{L}_{SM} + \delta\mathcal{L}_{SM}$$

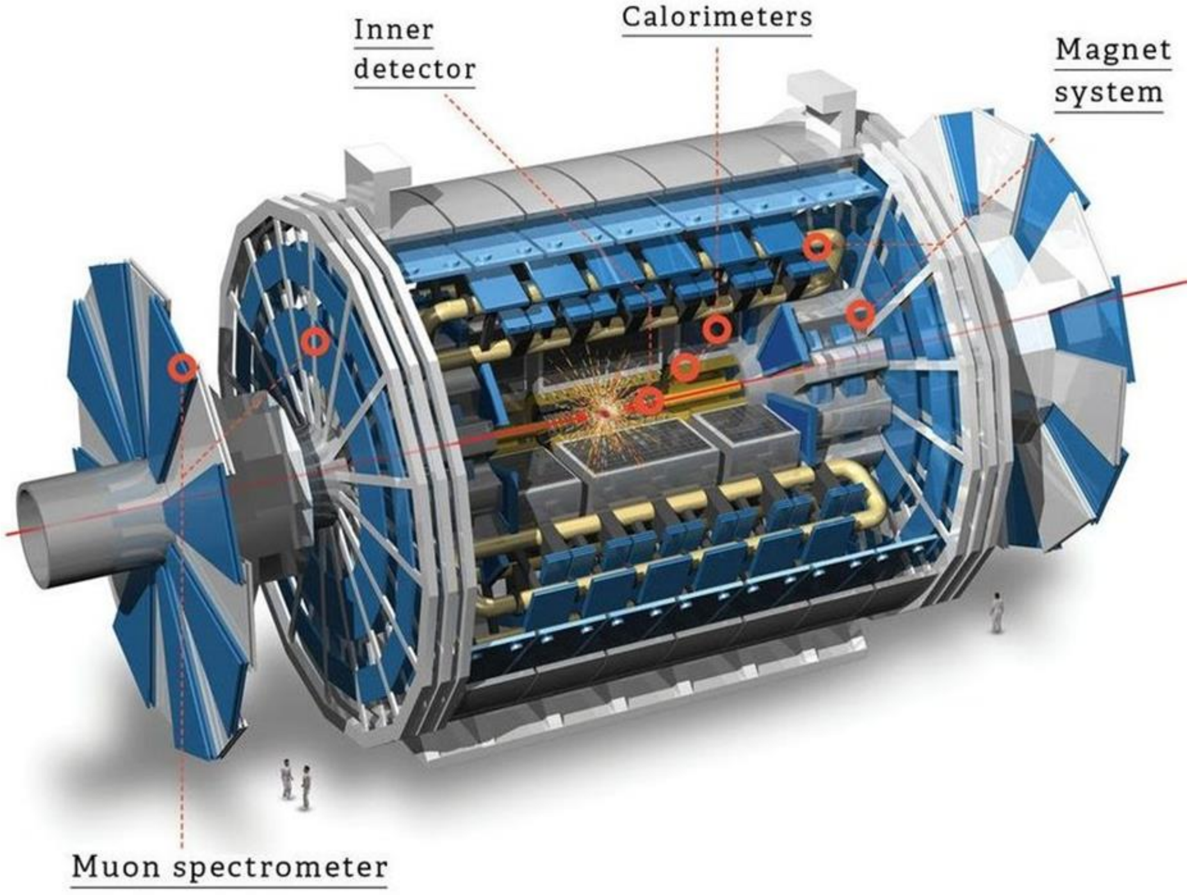
Starting from the Lagrangian of the Standard Model, made up of operators generated by the 4-dimensional fermion and boson fields, it is shown that $\delta\mathcal{L}_{SM}$ considers already known fermions and bosons and constructs with them new **operators of dimension 6**, respecting the symmetries of the Standard Model.



# ATLAS detector

## Where it is

ATLAS is one of the four large detectors present at the LHC in CERN in Ginevra.




## Components

1. **Internal detector**: measures direction, momentum and charge of particles produced in collisions
2. **Calorimeter**: contains all particles except neutrinos and muons and measures their energy
3. **Muon spectrometer**: measures the momentum of muons
4. **Magnet system**: deflects the trajectories of charged particles to measure their momentum and charge

## Trigger and data acquisition

For each collision the goal is to count, track and characterize all the particles produced. Two trigger levels:

1. **Hardware**: calorimeter and muon spectrometer information, it decides which data to keep and sends them to the second level
2. **Software**: it examines, selects and sends data to an offline storage system

# Artificial Neural Network

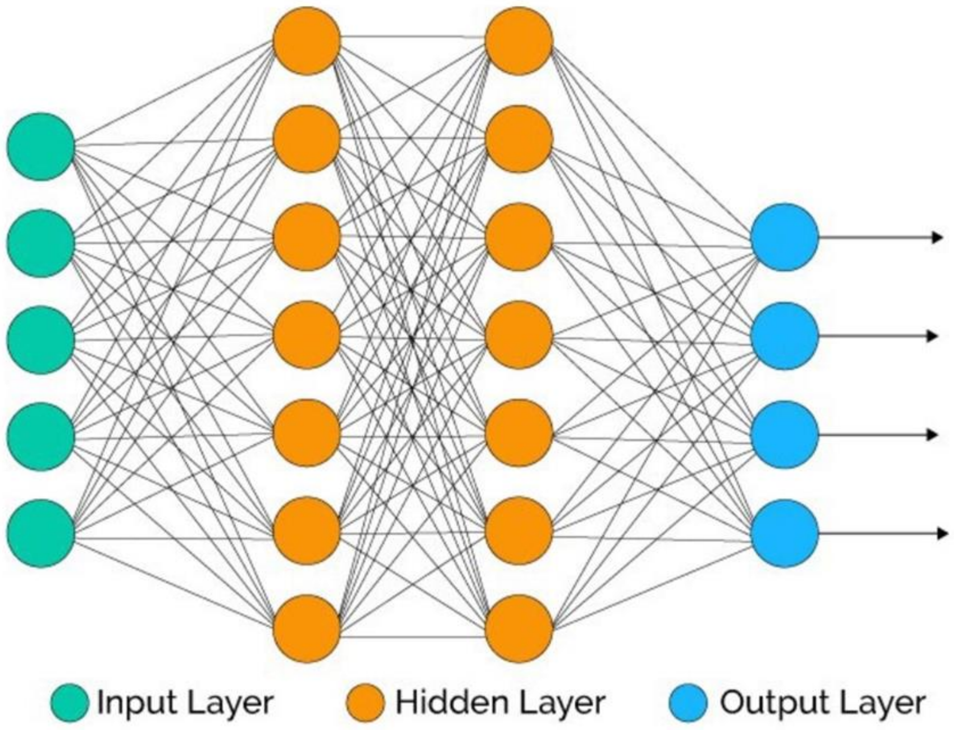
## How it works

A network is made up of **nodes** (artificial neurons) whose connections are regulated by numbers called **weights** which activate them (positive value) or suppress them (negative value) through an **input function**.
An **activation function** and a **threshold value** compute the output value of the neuron: an **algorithm** is thus modeled to produce a result for each input.

## Structure

Made up of different levels:

1. **Input layer**: receives information from the outside
2. **Hidden layers**: nodes receive information from input layer or other hidden layers and process them
3. **Output level**: the final result of all data processing, can have one or more nodes based on the problem studied




## Training

The network needs to be trained: new data are presented and for each training iteration the weights are modified so that it provides increasingly precise results.

# Data analysis

## Search for same-sign top quark signal with ATLAS

The process that produces quark top same-sign pairs starting from protons is:

$$pp \rightarrow tt \rightarrow W^+bW^+b \rightarrow l^+\nu bl^+\nu b$$

where $W^+$ is the mediator of the weak interaction, $b$ the bottom quark, $l^+$ a lepton (positron or muon) and $\nu$ the neutrino (electronic or muonic).

The searched signal should have particular characteristics:

1. a **pair of same-sign leptons**
2. two ***b*-jets** (it means adronic jets produced by the adronization of a bottom quark)
3. presence of **MET** (*Missing Transverse Energy*)

It is a **"clean" signal**, i.e. characterized by a very limited background, made up of events that could hide it for various reasons.

# Data analysis

## Choice of samples for analysis

Three sets of data have been proposed to the neural network:

1. high level (invariant masses, lepton angles, Ht and *b*-tagging)
2. strictly low-level (two-lepton and leading jet quadrivectors, number of jets and METs)
3. copy of the second case with the addition of two *b*-tagging variables (sumPsbtag and sumPsbtag77)

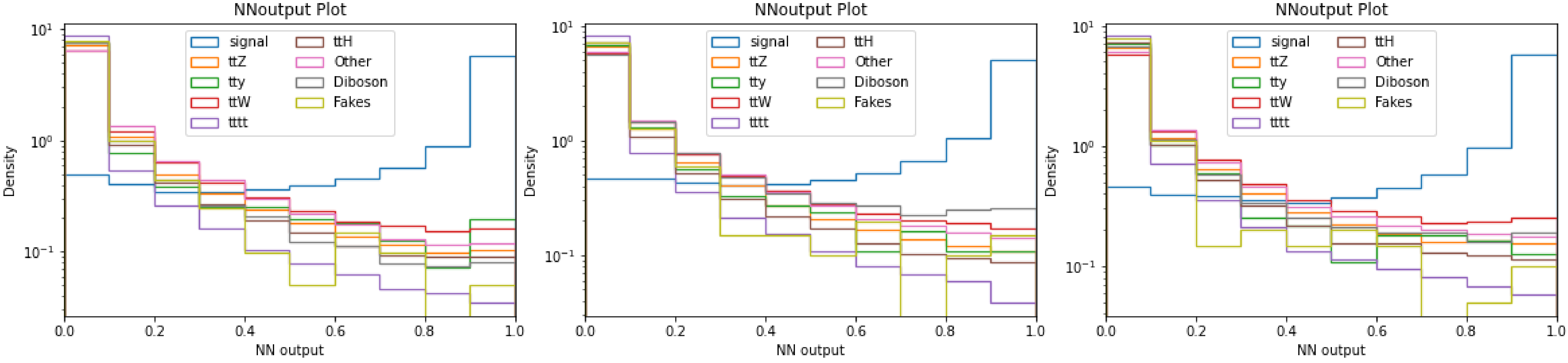
**GOAL: understand how the neural network behaves when you give it low-level or high-level variables as input.**

The neural network used was built using the keras and tensorflow python packages, it is composed of 5 hidden levels consisting of 128, 64, 32, 16 and 8 nodes respectively and has a single node in the output level since it is a classifier.

# Data analysis

## Comparisons between the different levels – Trend of the outputs of the NN

It is assumed that the second set of variables has a higher *VV* background (di-boson category) than the other two.




**SIGNAL → similar behaviour**

**BACKGROUNDS** → similar trend, small difference in the last two columns of the histograms:

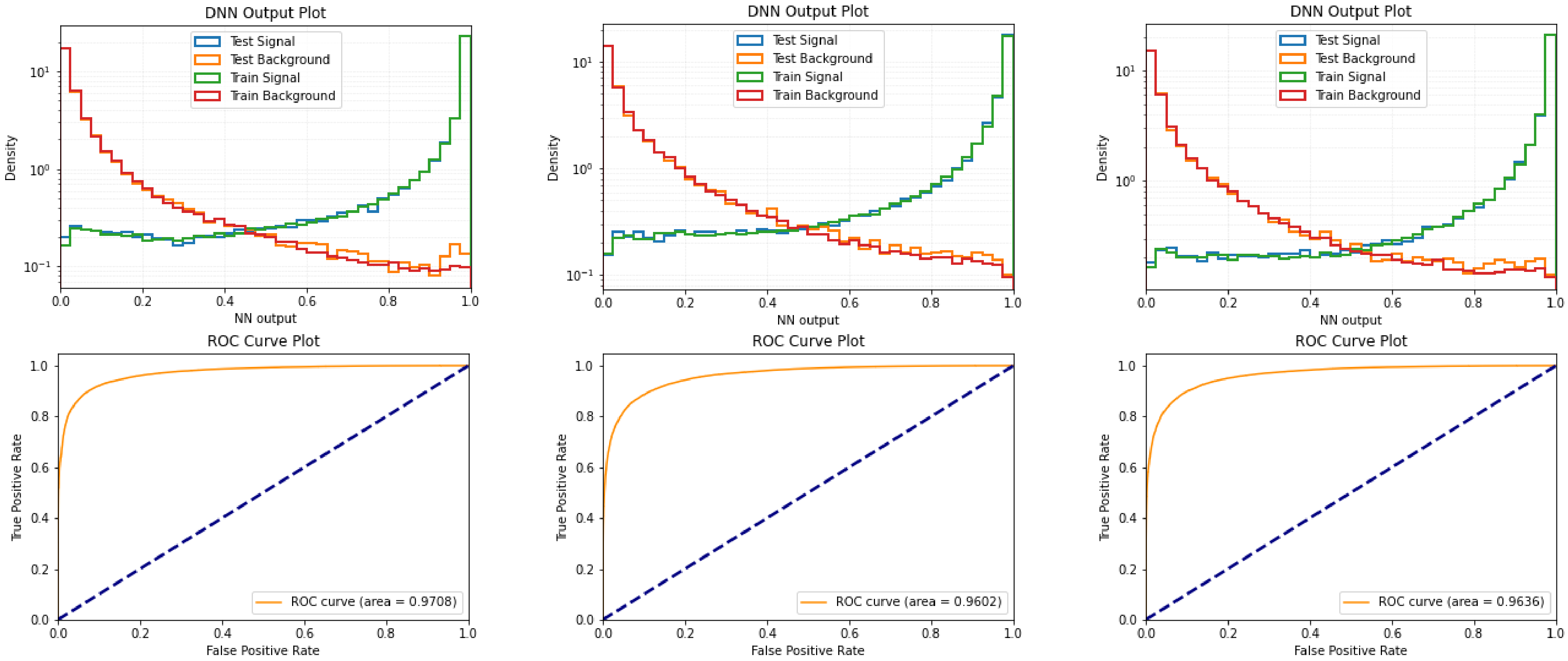
→ **second and third case higher values** assumed respectively by the ***VV*** and ***ttW* backgrounds**

→ *di-boson* background smaller in the third case wrt the second one

# Data analysis

## Comparisons between the different levels – Output behaviours and ROC curves

Similar behaviours althought high level variables show a better performance wrt the ones of low level while the latter appear to be more performant if are added *b*-tagging variables to them.



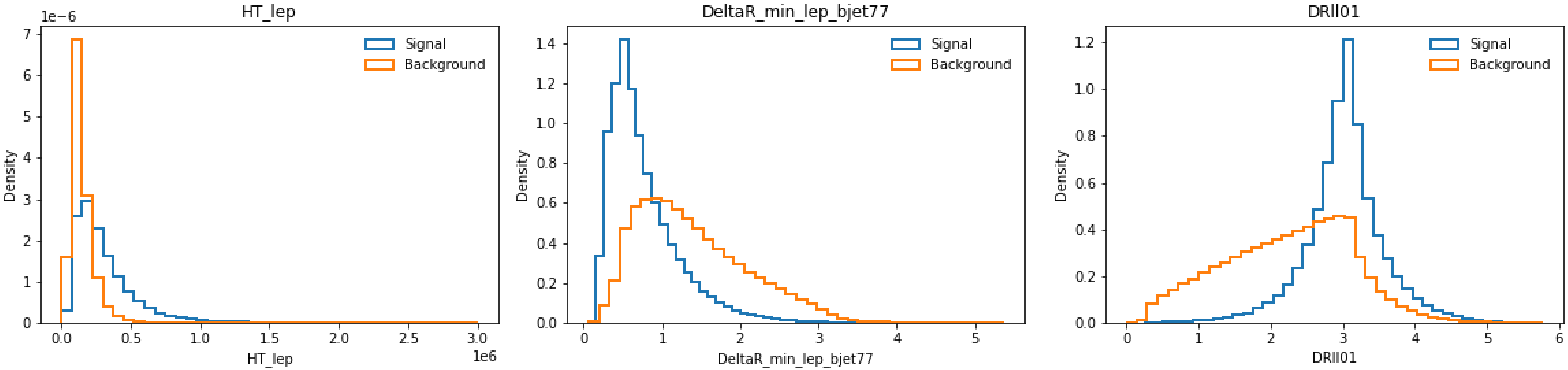

Areas under ROC curves, computed for each dataset, have the values **0.971** in the first case, **0.960** in the second and **0.964** in the third.

# Data analysis

## Comparisons between the different levels – Variables' behaviour

The trends of the most important variables considered by the neural network for the analysis were compared: **HT_lep**, **DeltaR_min_lep_bjet77** and **DRll01** for **HIGH LEVEL**; **lep_Phi_1**, **lep_Phi_0** and **njets_OR** for the **LOW LEVEL**, even after the introduction of the two *b*-tagging variables.

## HIGH LEVEL




The network exploits the strong discriminating power of the input variables.

# Data analysis

## Comparisons between the different levels – Variables' behaviour

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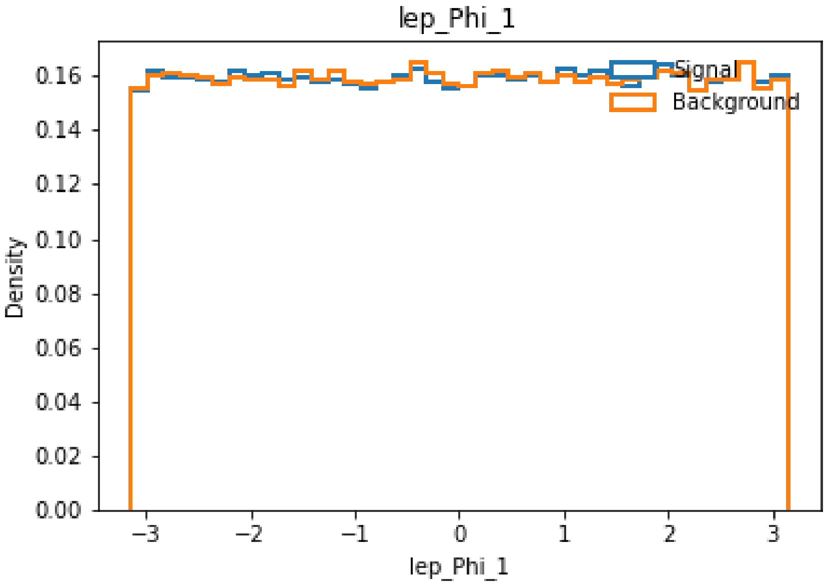
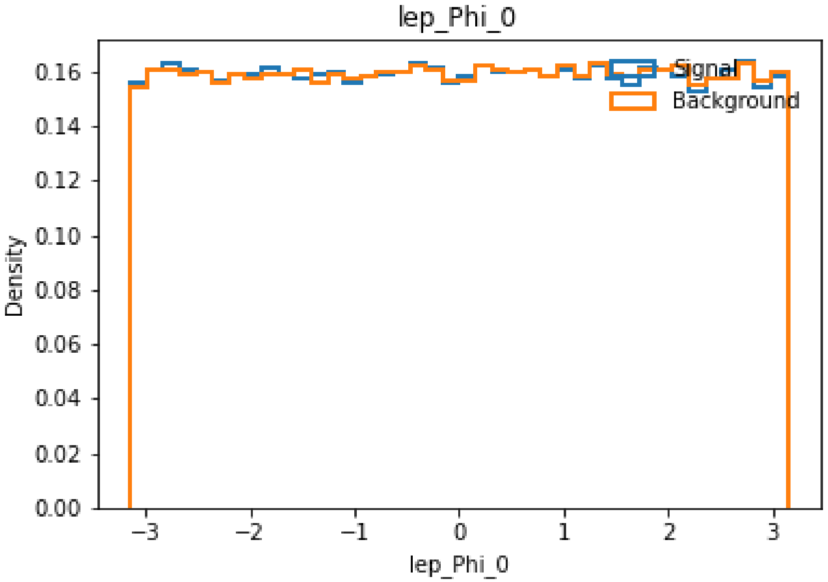
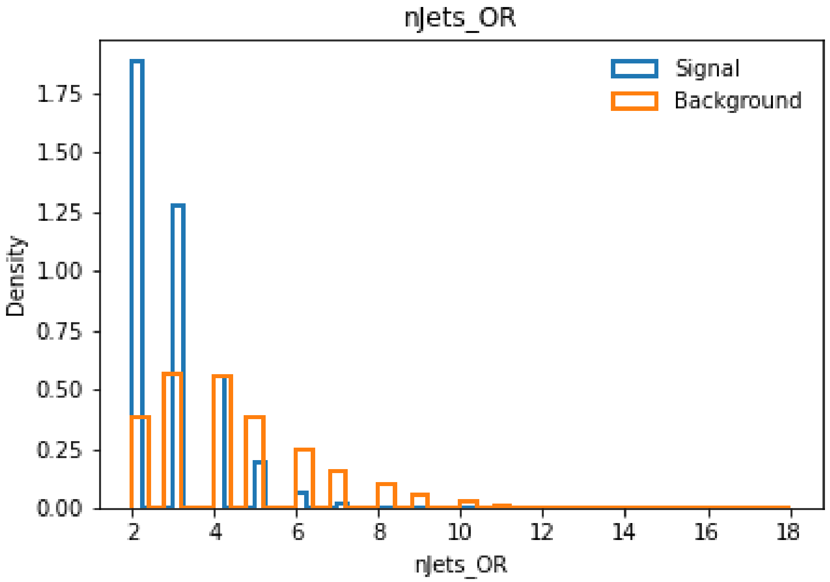
## LOW LEVEL




The network reconstructs and exploits the strong correlations existing between the low-level variables for signal and background discrimination.

# Conclusions

A study on the performance of an artificial neural network was conducted in the context of the search for same-sign top quarks with the ATLAS experiment at the LHC.

- Use of an artificial neural network for signal/background discrimination
- Using three datasets with different levels of reconstruction
- Performance study for the various levels of reconstruction

Comparable results for the various levels of reconstruction: the neural network is able to exploit the correlations between the low-level variables, providing a high discriminating power between the signal and background hypotheses.

The results presented here are a starting point for a more in-depth study that can be used in the comprehensive analyses of the ATLAS collaboration.

# Thanks for the attention