UiO : Fysisk institutt
Det matematisk-naturvitenskapelige fakultet

Application of Supervised Machine Learning to the Search for New Physics in ATLAS data

A Study of Ordinary Dense, Parameterized and Ensemble Networks and their Application to High Energy Physics

William Hirst **May 19, 2023**

Outline

Overview

Outline

Why apply machine learning to HEP problems?

How do we search for new physics?

Outline

A summary of the applied methods

Three neural network variants

- Ordinary dense neural network
- Ensemble networks utilizing Local-Winner-Takes-All (LWTA) layers
- Parameterized neural networks (PNN)

One boosted decision tree method

- XGBoost using default settings

How are the methods compared?

Training strategy

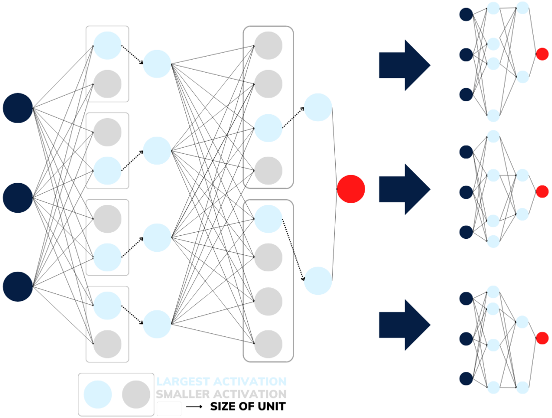
Outline

An introduction and study of each method

Ordinary dense neural network

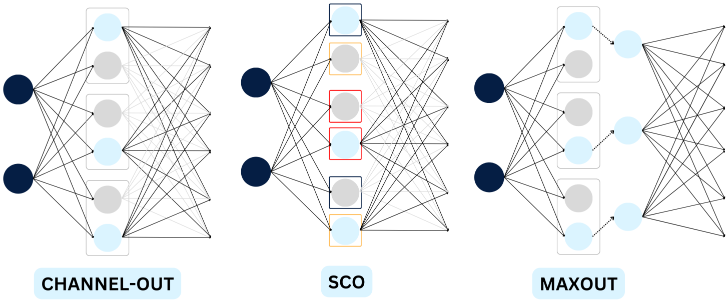
Ensemble methods - LWTA

- Dropout
- What is LWTA?
- Competing nodes - Units
- Encode information in pattern specific pathways



Channel-Out, SCO and Maxout

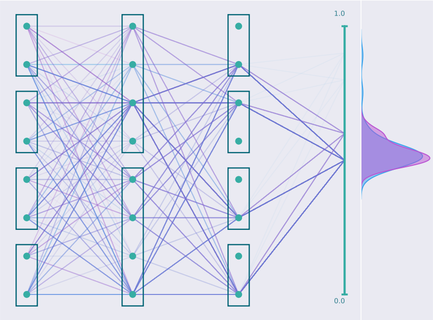
Layer	Separate Weights & Biases	Static Units
Channel-Out	*Yes*	*Yes*
SCO	*Yes*	*No*
Maxout	*No*	*Yes*



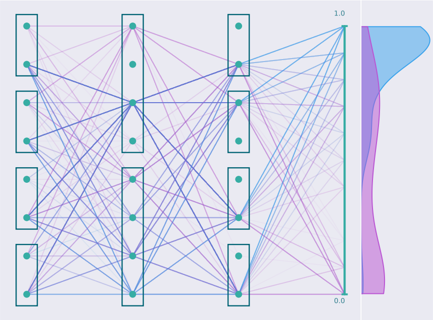
Visualization and study of sparse pathways

- A study of the implementation and effect of LWTA layers
- Visualize the activation and paths of 100 randomly sampled events
  - 50 background
  - 50 signal
- The bolder the line the more frequently the path is used.

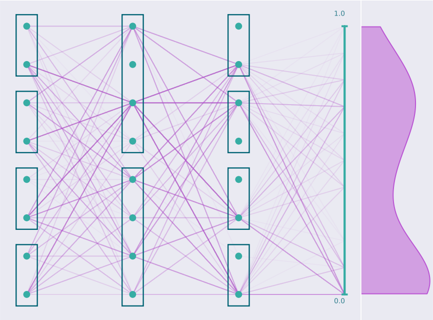
Before training



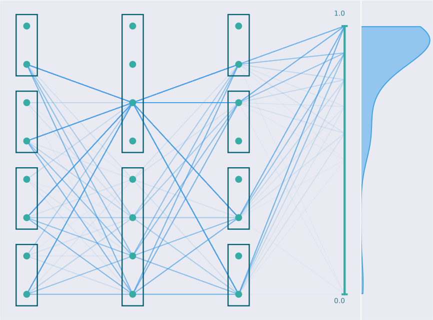
After training



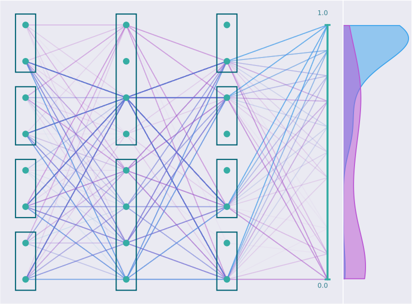
Background



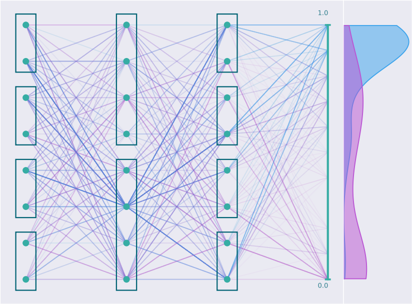
Signal



Comparing activation of Maxout with SCO



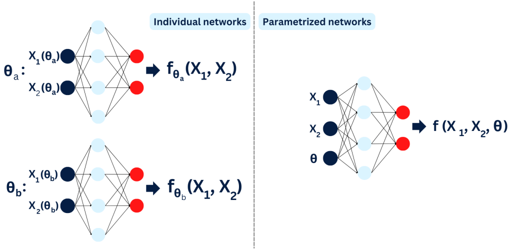
Maxout



SCO

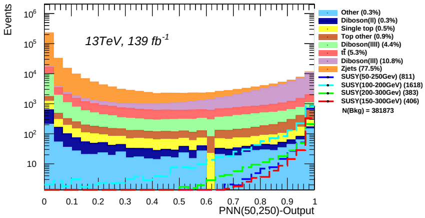
Parameterized neural network

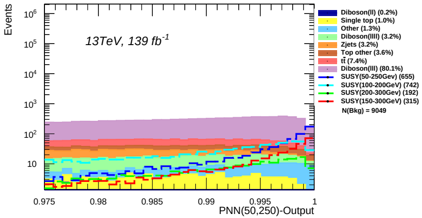
- For diverse data set, X, dependent on a parameter, $X(\theta)$
  - Classical approach: One model for each parameter
  - PNN approach: Include θ as feature in feature set
- Signal events using masses $\{A, B\}_{GeV}$ to generate event during simulation will include the parameters A and B in feature set
- Background assigned parameters randomly using same distribution as signal
- Motivation
  - Network will associate parameters with trends in the data

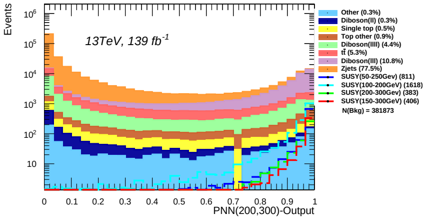


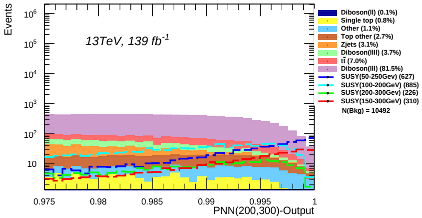
Study the effect of the parameters in the PNN

- Study if the parameters effect the training as intended
- Test: Manually assign all the events, both background and signal, the same parameters (mass combinations) thereby assigning most of the signal the wrong parameters
- Hypothesis: PNN performs better when events are assigned correct parameters
- First test: All events are given parameters $\{50, 250\}_{GeV}$
- Second test: All events are given parameters $\{200, 300\}_{GeV}$


13TeV, 139 fb-1
Other (0.3%)
Diboson(ll) (0.3%)
Single top (0.5%)
Top other (0.9%)
Diboson(llll) (4.4%)
tt̄ (5.3%)
Diboson(lll) (10.8%)
Zjets (77.5%)
SUSY(50-250Gev) (811)
SUSY(100-200GeV) (1618)
SUSY(200-300GeV) (383)
SUSY(150-300GeV) (406)
N(Bkg) = 381873
Events
PNN(50,250)-Output

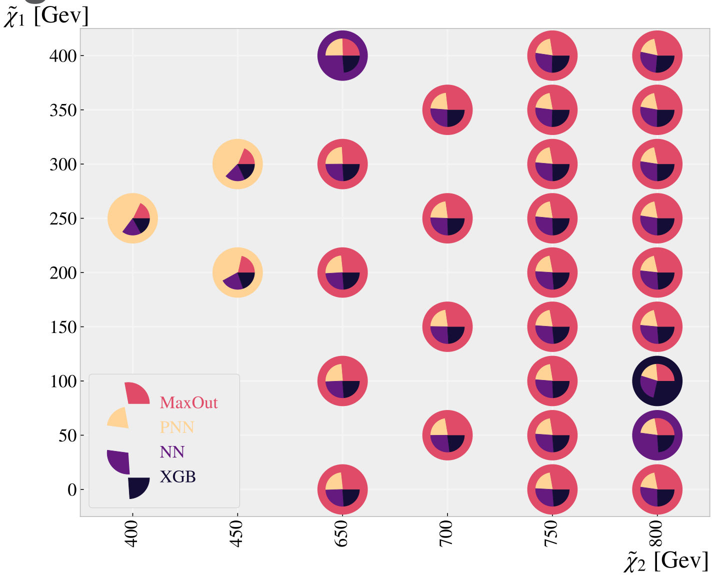

13TeV, 139 fb-1
Diboson(ll) (0.2%)
Single top (1.0%)
Other (1.3%)
Diboson(llll) (3.2%)
Zjets (3.2%)
Top other (3.6%)
tt̄ (7.4%)
Diboson(lll) (80.1%)
SUSY(50-250Gev) (655)
SUSY(100-200GeV) (742)
SUSY(200-300GeV) (192)
SUSY(150-300GeV) (315)
N(Bkg) = 9049
Events
PNN(50,250)-Output


13TeV, 139 fb-1
Other (0.3%)
Diboson(ll) (0.3%)
Single top (0.5%)
Top other (0.9%)
Diboson(llll) (4.4%)
tt̄ (5.3%)
Diboson(lll) (10.8%)
Zjets (77.5%)
SUSY(50-250Gev) (811)
SUSY(100-200GeV) (1618)
SUSY(200-300GeV) (383)
SUSY(150-300GeV) (406)
N(Bkg) = 381873
Events
PNN(200,300)-Output


13TeV, 139 fb-1
Diboson(ll) (0.1%)
Single top (0.8%)
Other (1.1%)
Top other (2.7%)
Zjets (3.1%)
Diboson(llll) (3.7%)
tt̄ (7.0%)
Diboson(lll) (81.5%)
SUSY(50-250GeV) (627)
SUSY(100-200GeV) (885)
SUSY(200-300GeV) (226)
SUSY(150-300GeV) (310)
N(Bkg) = 10492
Events
PNN(200,300)-Output

Boosted decision trees - XGBoost

Comparing the sensitivity on a subset of the signal



Increasing sensitivity through a PCA

Comparing the methods to previous analysis

Outline

References I

Hartshorne, R.
Algebraic Geometry.
Springer-Verlag, 1977.

Helsø, M.
'Rational quartic symmetroids'.
Adv. Geom., 20(1):71–89, 2020.

Helsø, M. and Ranestad, K.
Rational quartic spectrahedra, 2018.
https://arxiv.org/abs/1810.11235

- Atiyah, M. and Macdonald, I.
Introduction to commutative algebra.
Addison-Wesley Publishing Co., Reading, Mass.-London-Don Mills, Ont., 1969

References II

[5] Artin, M.
'On isolated rational singularities of surfaces'.
Amer. J. Math., 80(1):129–136, 1966.

UiO : Fysisk institutt
Det matematisk-naturvitenskapelige fakultet

William Hirst

Application of Supervised Machine Learning to the Search for New Physics in ATLAS data

A Study of Ordinary Dense, Parameterized and Ensemble Networks and their Application to High Energy Physics