Search for New Physics with Anomaly Detection approach at the LHC

Thesis defense 23/09/2024

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Table Of Contents

Part 01

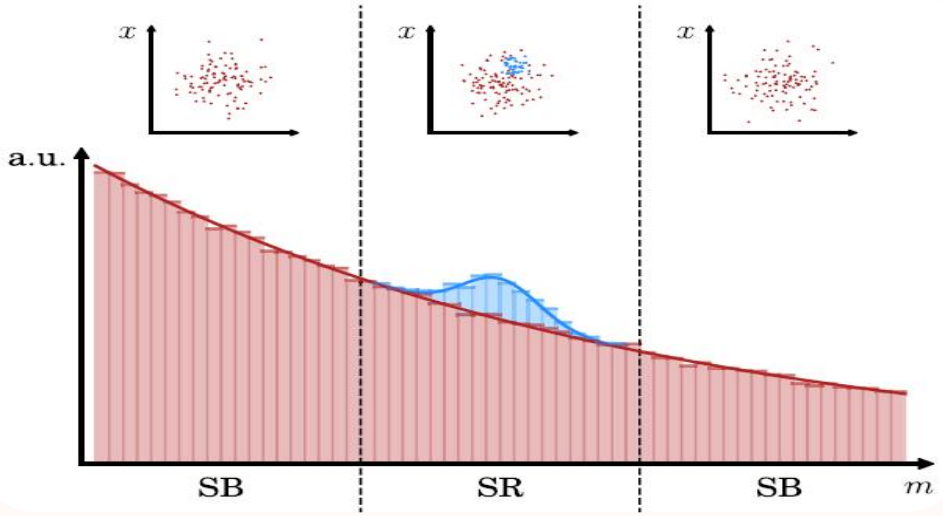
Anomaly Detection

Anomalies are data with no normal behavior

Looking for outliers

What is an outliner?

"An outlier is an observation which deviates so much from other observations as to arouse suspicions that it was generated by a different mechanism."
Hawkins, Identification of Outliers (1980)



Trying to answer many questions left after the discovery of the Higgs boson

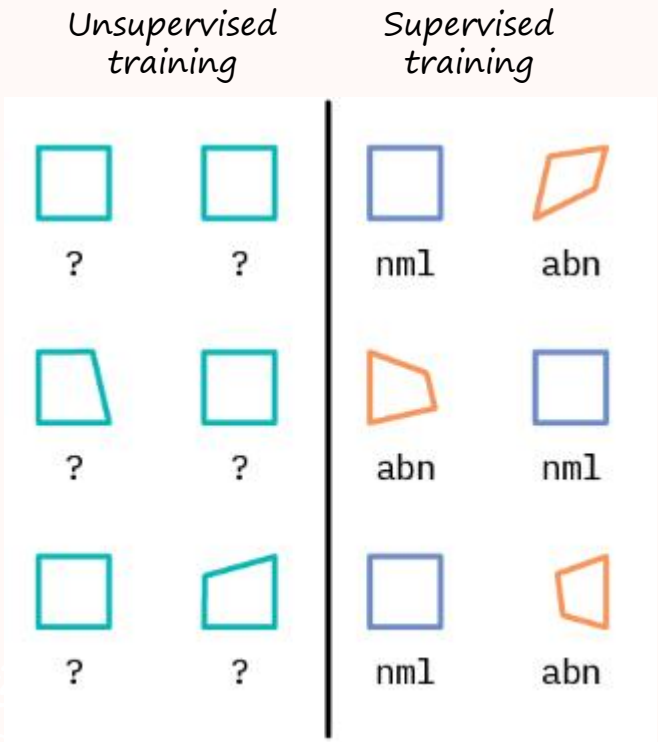
Model agnostic: it does not rely on a specific theoretical model.

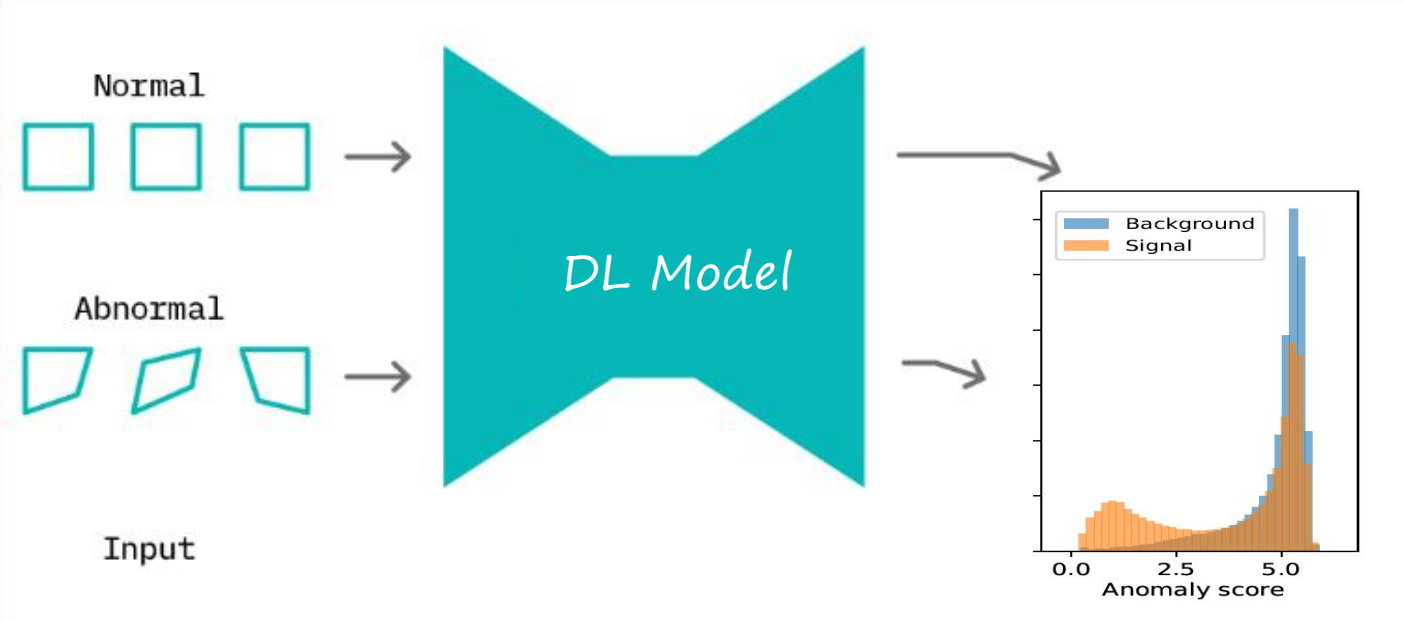
Where is the church?

Rome from the Janiculan Hill

How is it done?

Supervised vs Unsupervised





Model is trained over normal/background events only, then it is tested over normal and anomaly data

Reconstruction loss distribution is used to estimate model perfomances and discrimanate between background and signal

Part 02

Dataset

1.1 M events analysed

LHC Olympics 2020 dataset

What does the original dataset look like?

Background events:

1 M events *pp --> jet jet*

QCD events

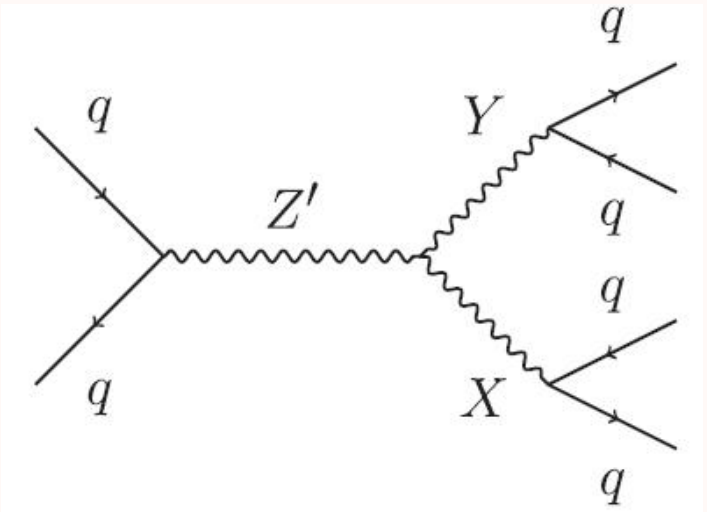
Signal events:

100 k events

pp -> Z' -> XY -> jet-jet

Data generated in a MonteCarlo simulation Delphes

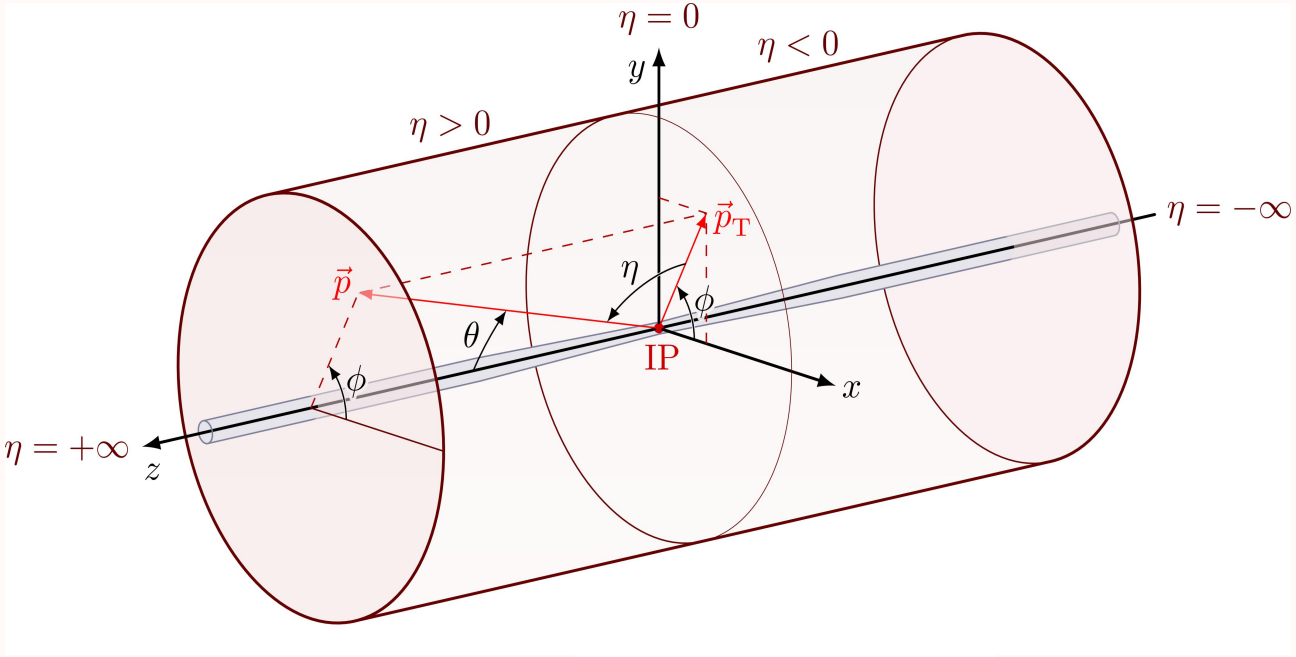
Data are detector coordinates (pT, eta, phi);
Events zero padded to 700 particles -> array (1.1M,2101)

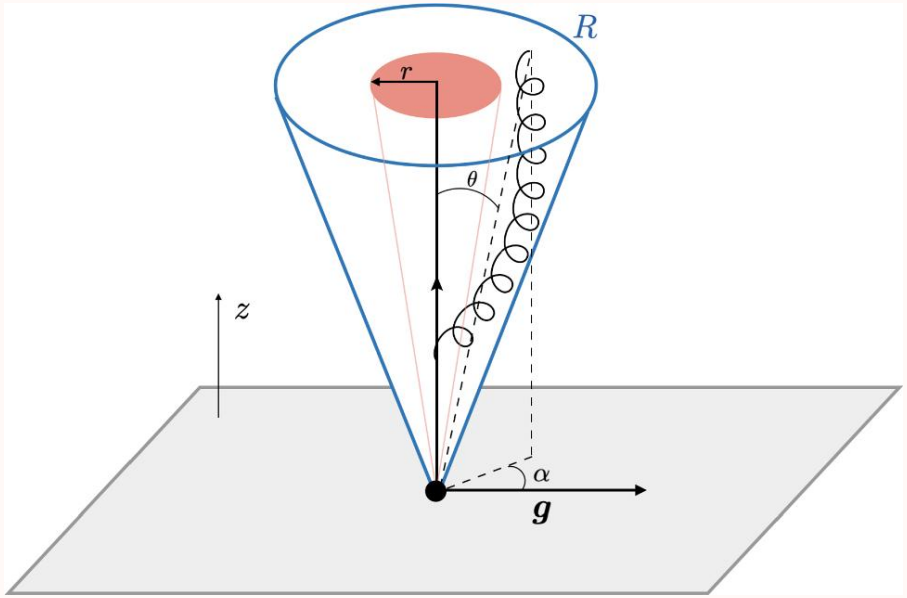


A resonance is used in the signal dataset because the dijet final state offers a complex topology for hiding new physics

Coordinates and jet reconstruction

Reconstruction applied to data





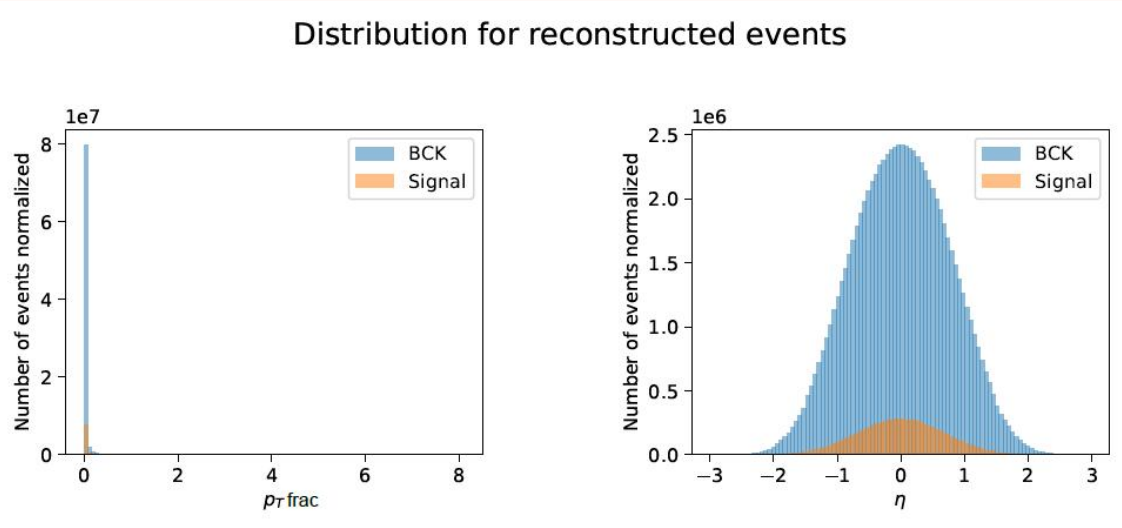
$$\eta = -ln\left(tan\frac{\theta}{2}\right)$$

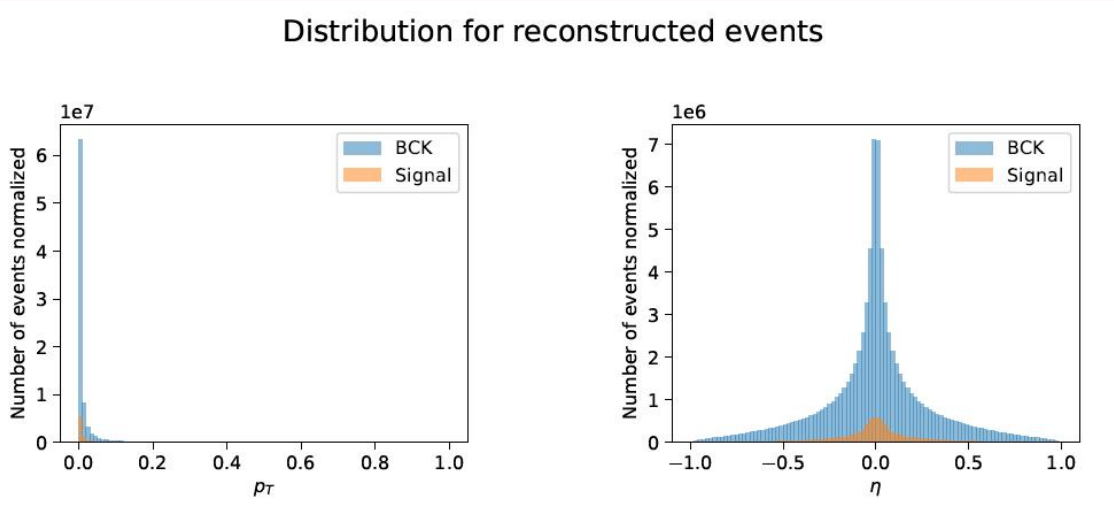
Reconstruction radius R=1

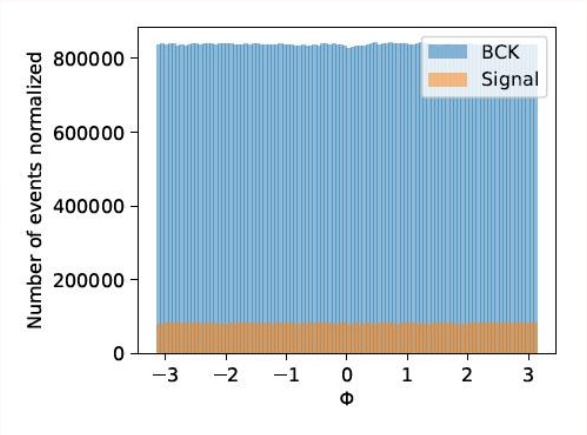
For each one of the 1.1M events, 2 leading jet are selected, so we get: 2.2 M data after algorithm

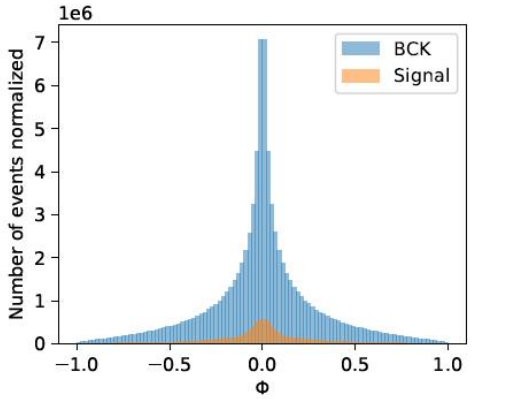
Data distribution

Data before (left) and after (right) rotation









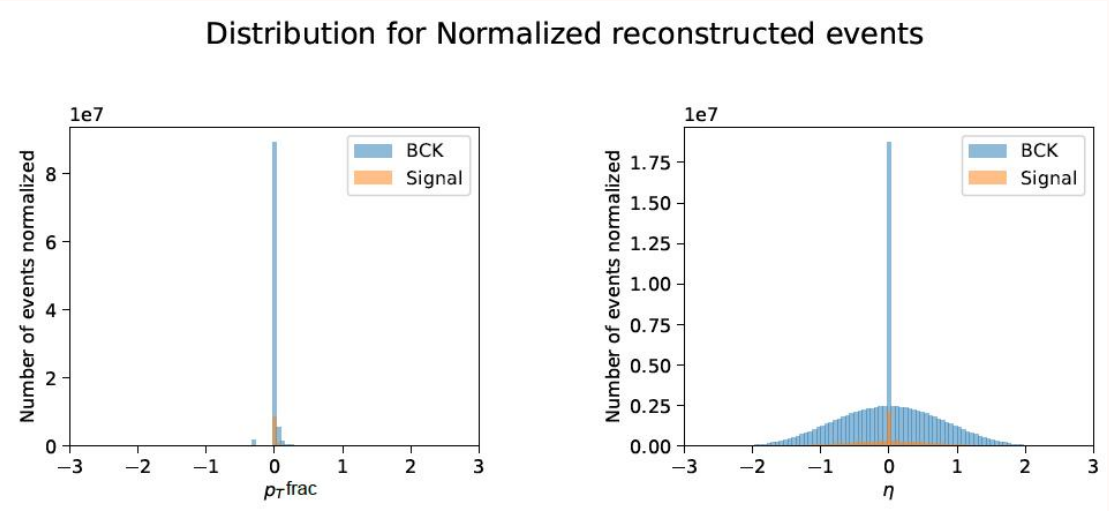
Rotation of constituents along jet axis

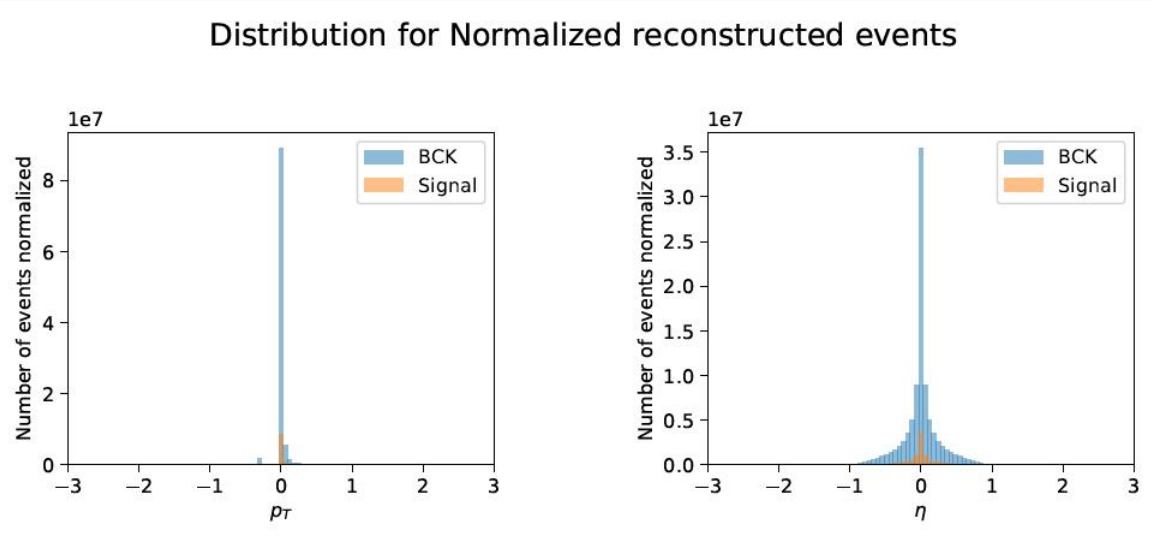
before

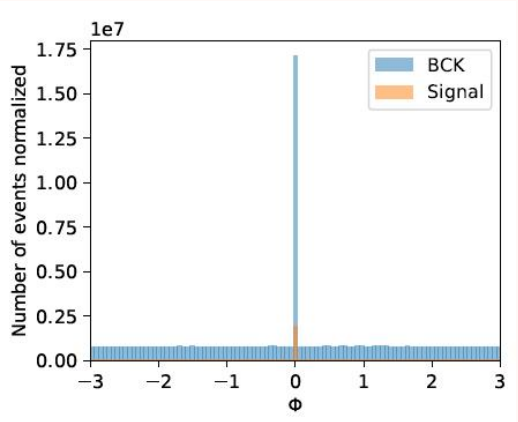
after

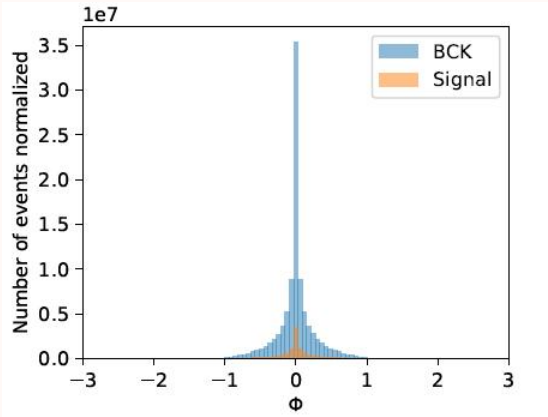
Normalized data

Distribution for normalized data, before (left) and after (right) rotation









Standard scaler:

$$\widetilde{x} = \frac{x - < x >}{\sigma_x}$$

where x= pt, η, Φ

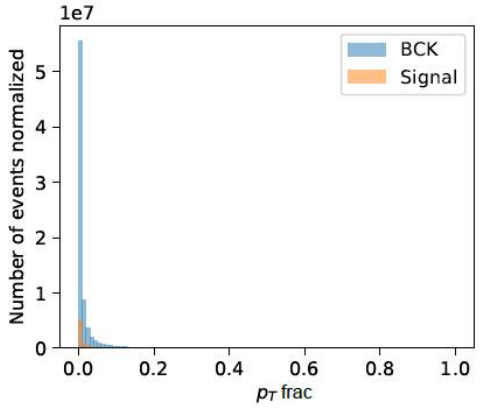
before

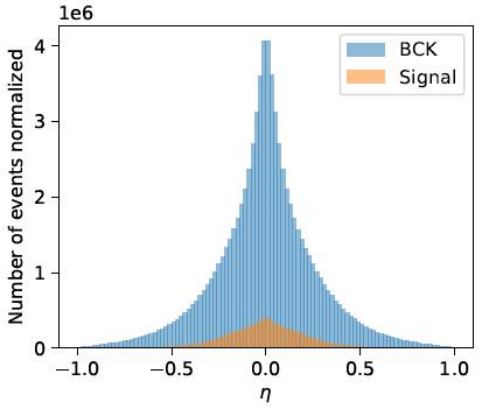
after

Tranformed data

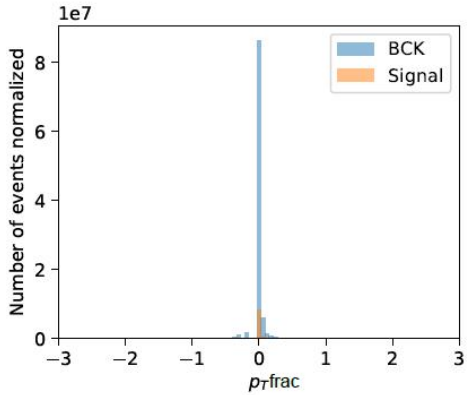
Distribution for transformed data, before (left) and after (right) normalization

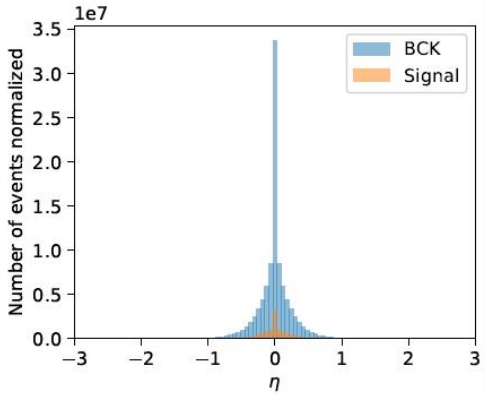
Distribution for reconstructed events

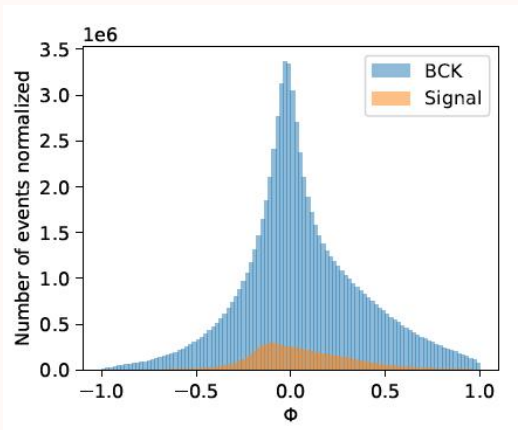


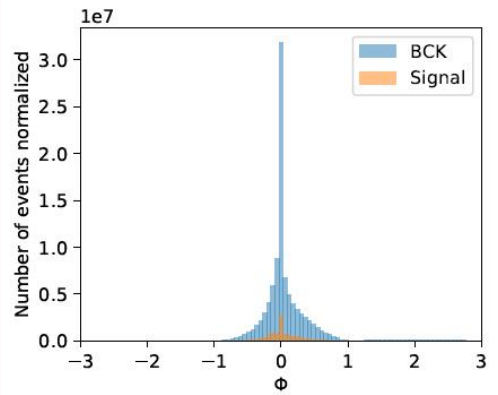


Distribution for Normalized reconstructed events









$m_0 = 250$ MeV
$E_0 = 1$ GeV
$\eta' = 0$, $\Phi' = 0$

Based on: "A robust anomaly finder based on autoencoders"
T.S. Roy et A.H. Vijay

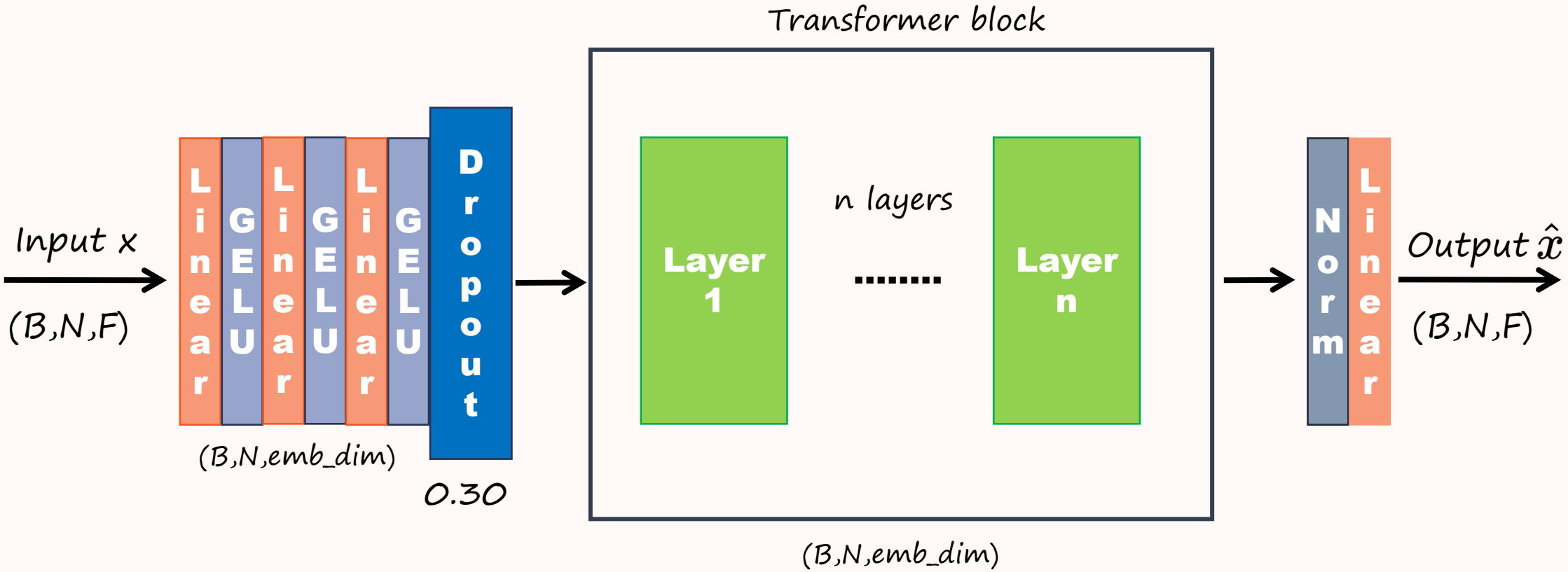
Part 03

Model

"Attention is all you need"

Transformer architecture

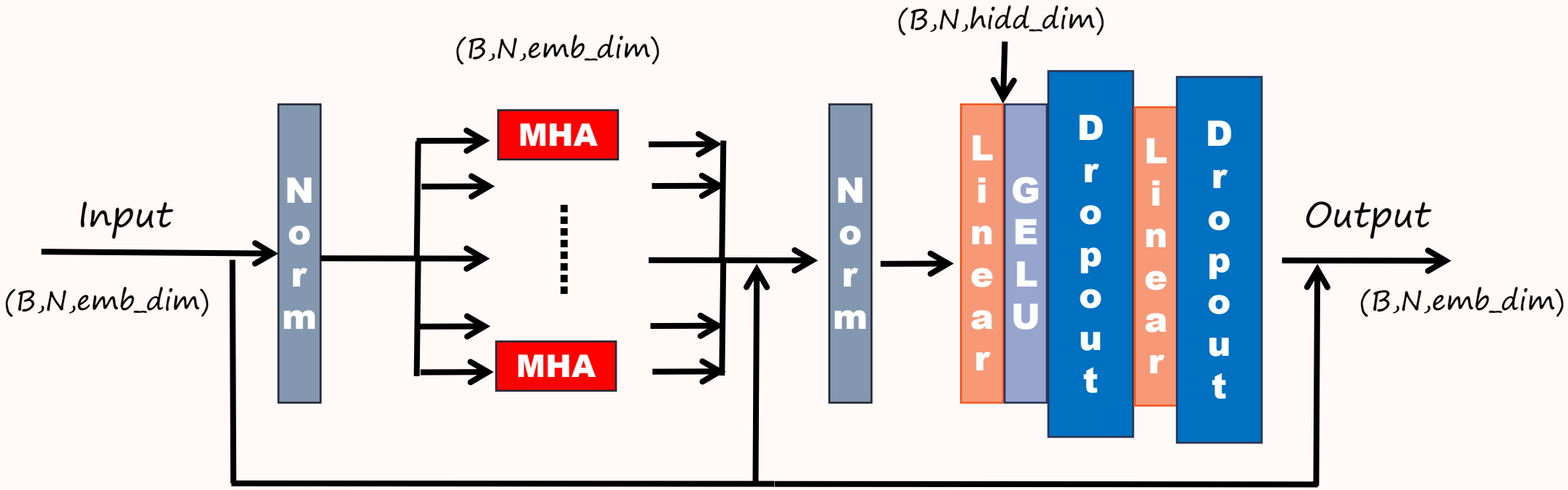
What is it inside the model?



B=batch size_>512; N=constituents->50; F=Features->3
Input dim=3, embed dim=128, hidden dim=256
n layers= 5-32-4; num head= 8-8-2 (normal-rotated-tranformed)

Attention Block

Let's look inside a layer



Based on: "Attention is all you need" by A. Vaswani, N. Shazeer, N. Parmar, J. Uszkoreit, L. Jones, A. Gomez, L. Kaiser and I. Polosukhin

Part 04

Training

How does the model learn?

Parameters and loss

Unsupervised training

Set	BCK	Signal
Training	72.7% = 1.6M	0%
Validation	9.1% = 200k	0%
Testing	9.1% = 200k	9.1% = 200k

$$MSE_{loss} = ||x - \hat{x}||^2$$

$$AS = ||x - \hat{x}||$$

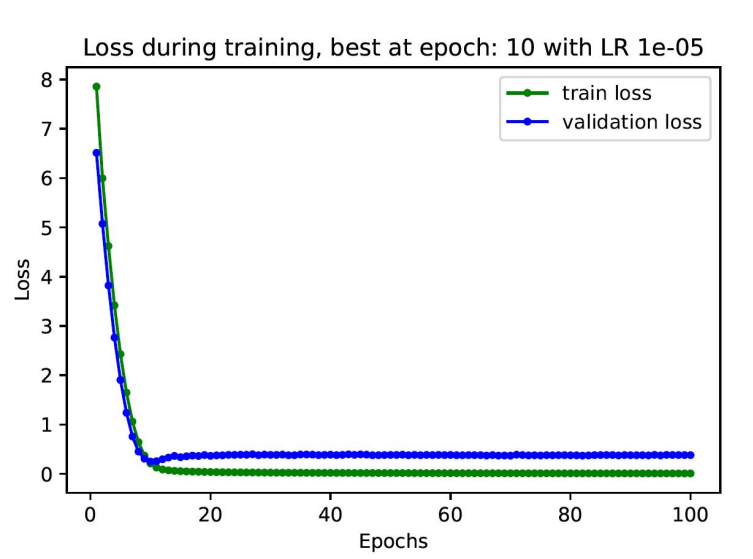
linalg.norm -> Frobenius norm

Num epochs = 50

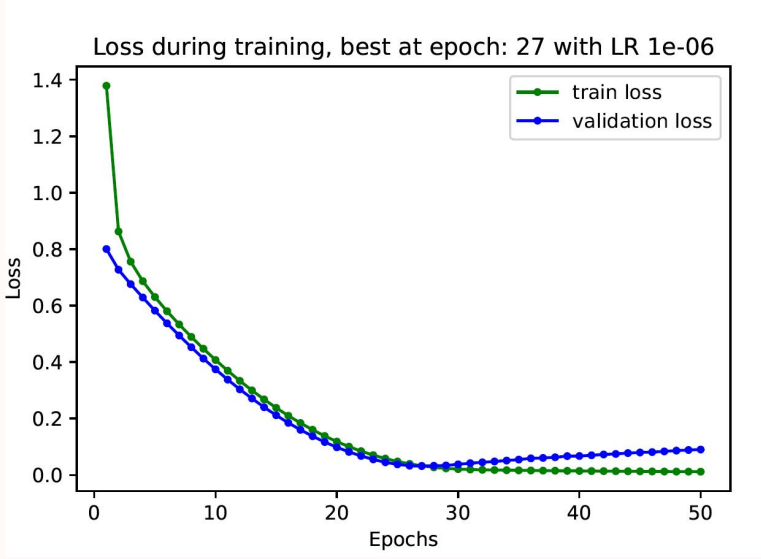
LearningRate = 1e-6

Training results

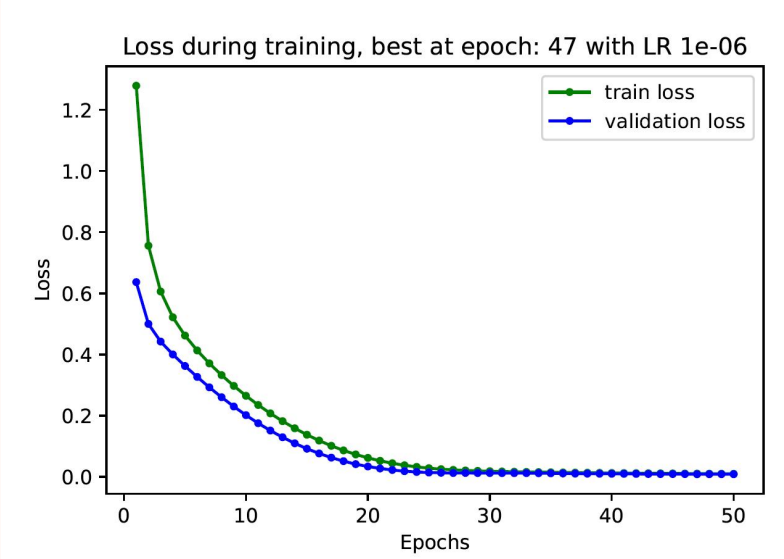
What did we get after training loop?



anti-k_T dataset



rotated dataset

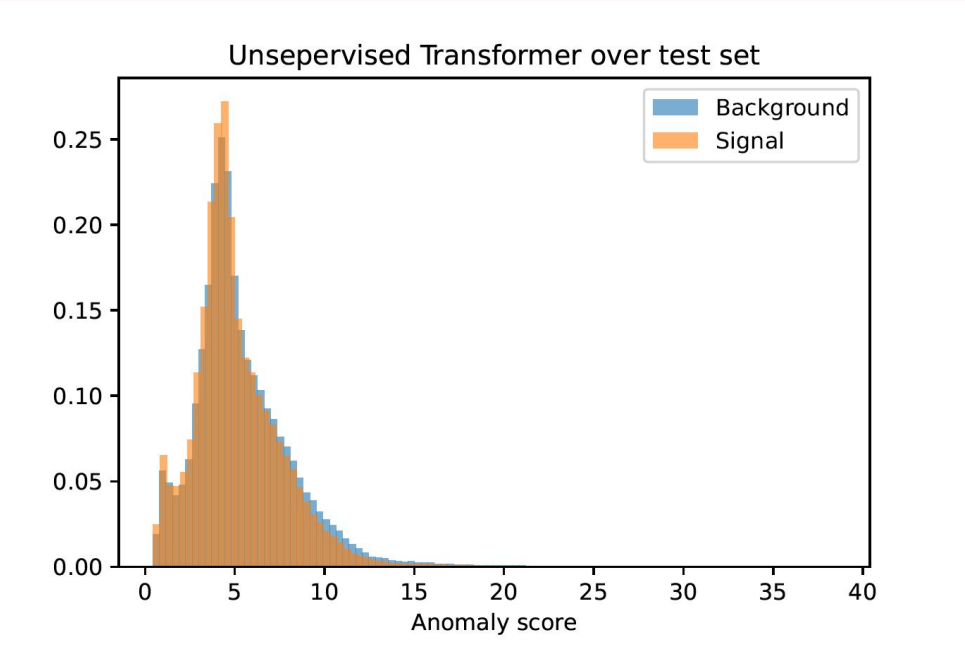


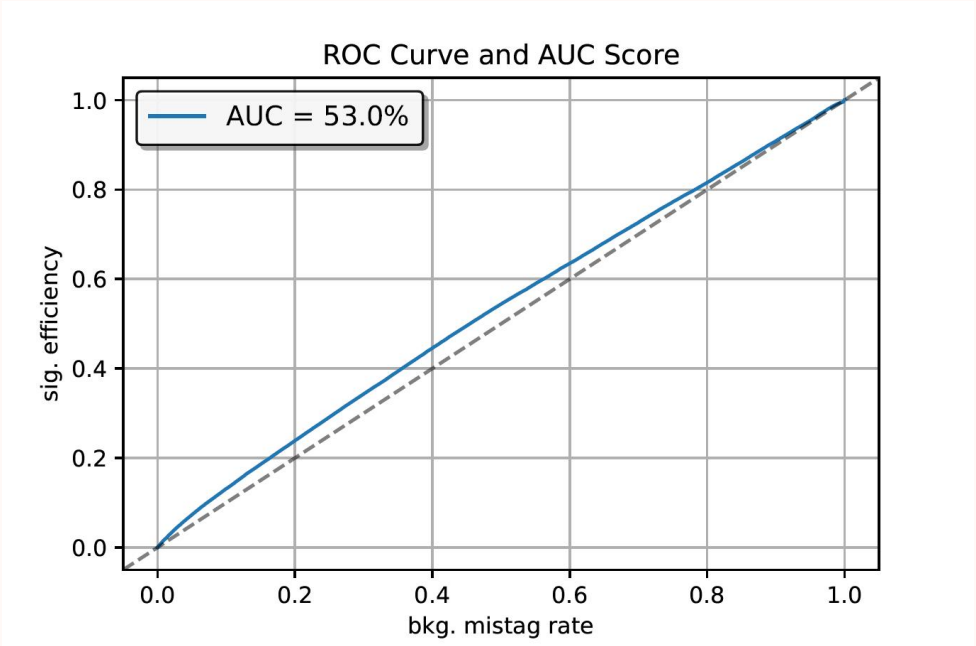
transformed dataset

Overfitting-->less training epochs needed

Results without rotation

If we don't apply rotation, we get...



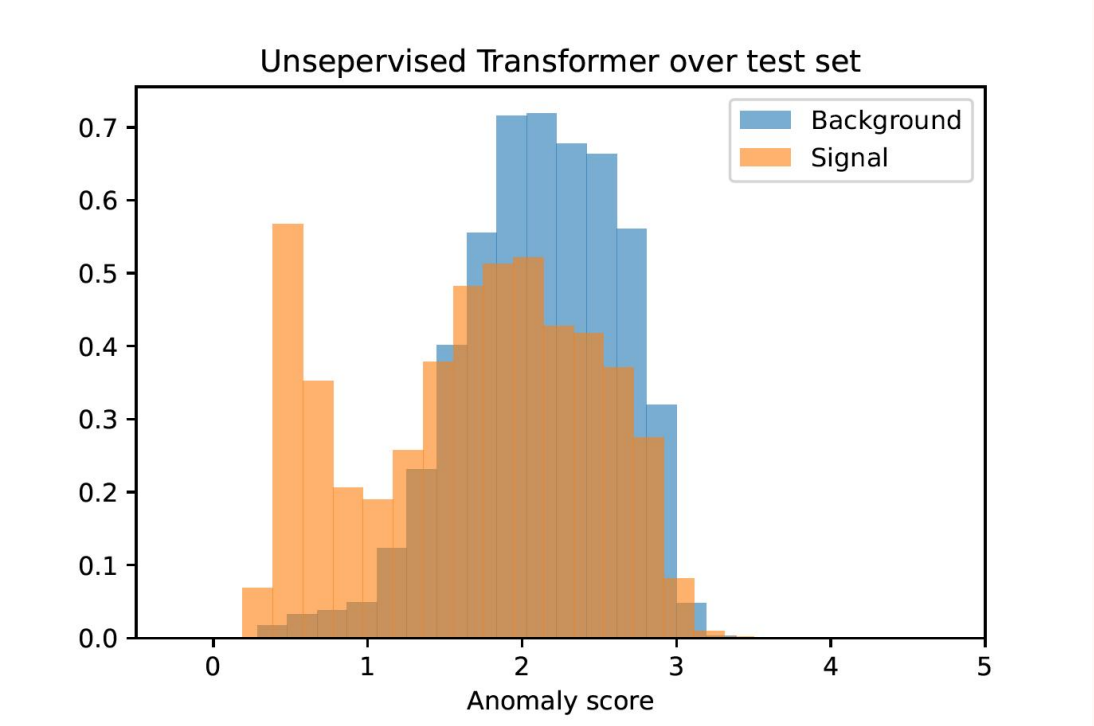


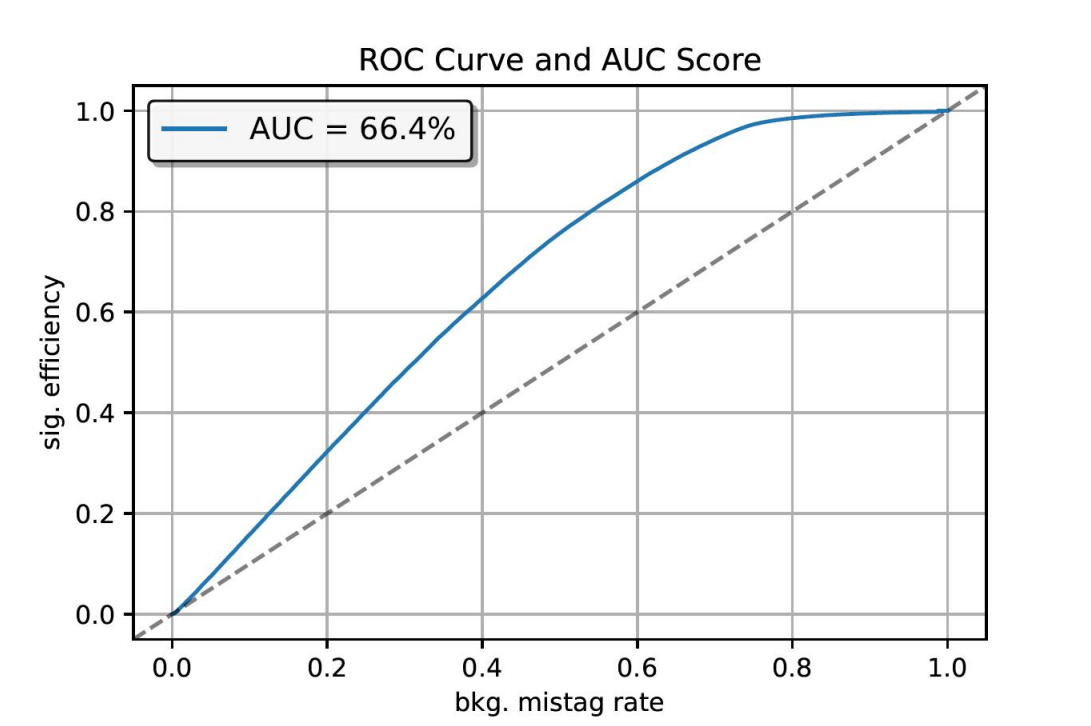
No detection at all!!!

$$TPR = \frac{TP}{TP + FN} \quad , \quad \mathrm{FPR} = \frac{\mathrm{FP}}{\mathrm{FP} + \mathrm{TN}}$$

Results with rotation

If we apply rotation, we get...

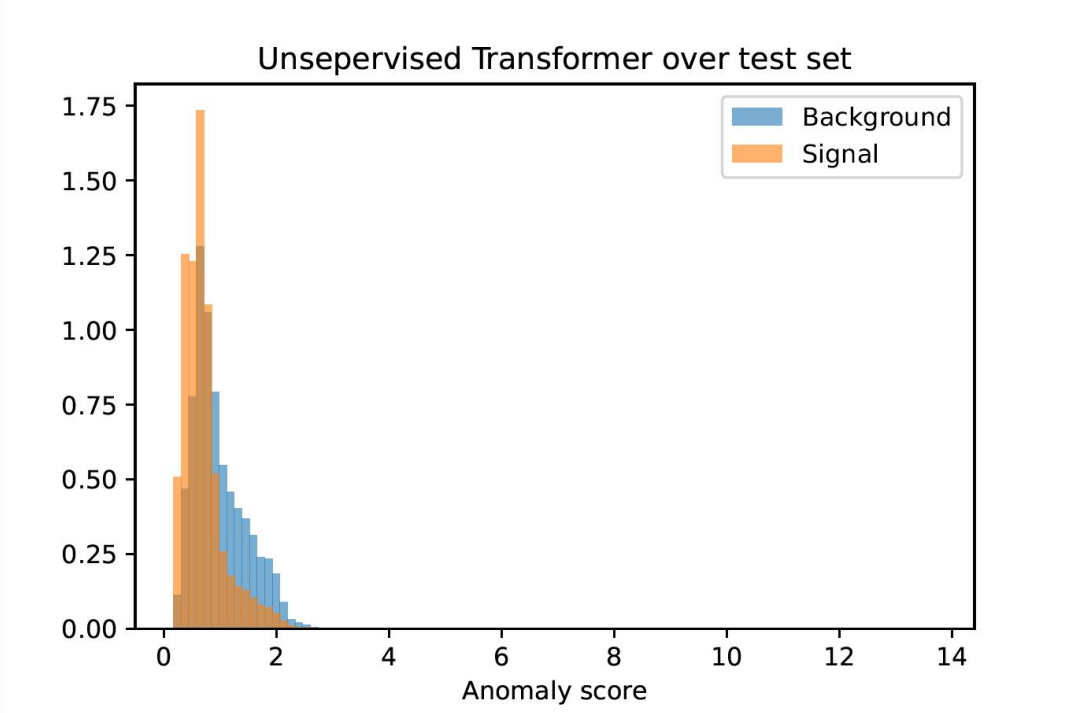


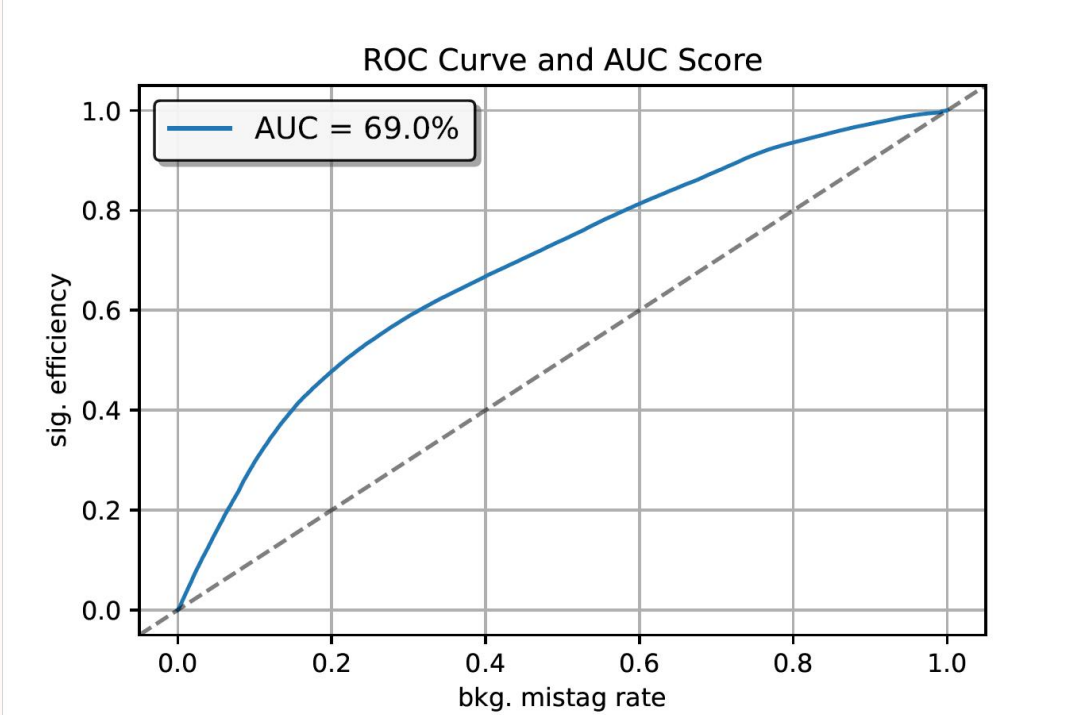


Significant imporovement but not the best

Results with transformation

If we transform our data, do we find a new particle?





The best result: detection

Thanks for the attention

Valerio Tinari