

Identifying Emerging Jets at the ATLAS Experiment

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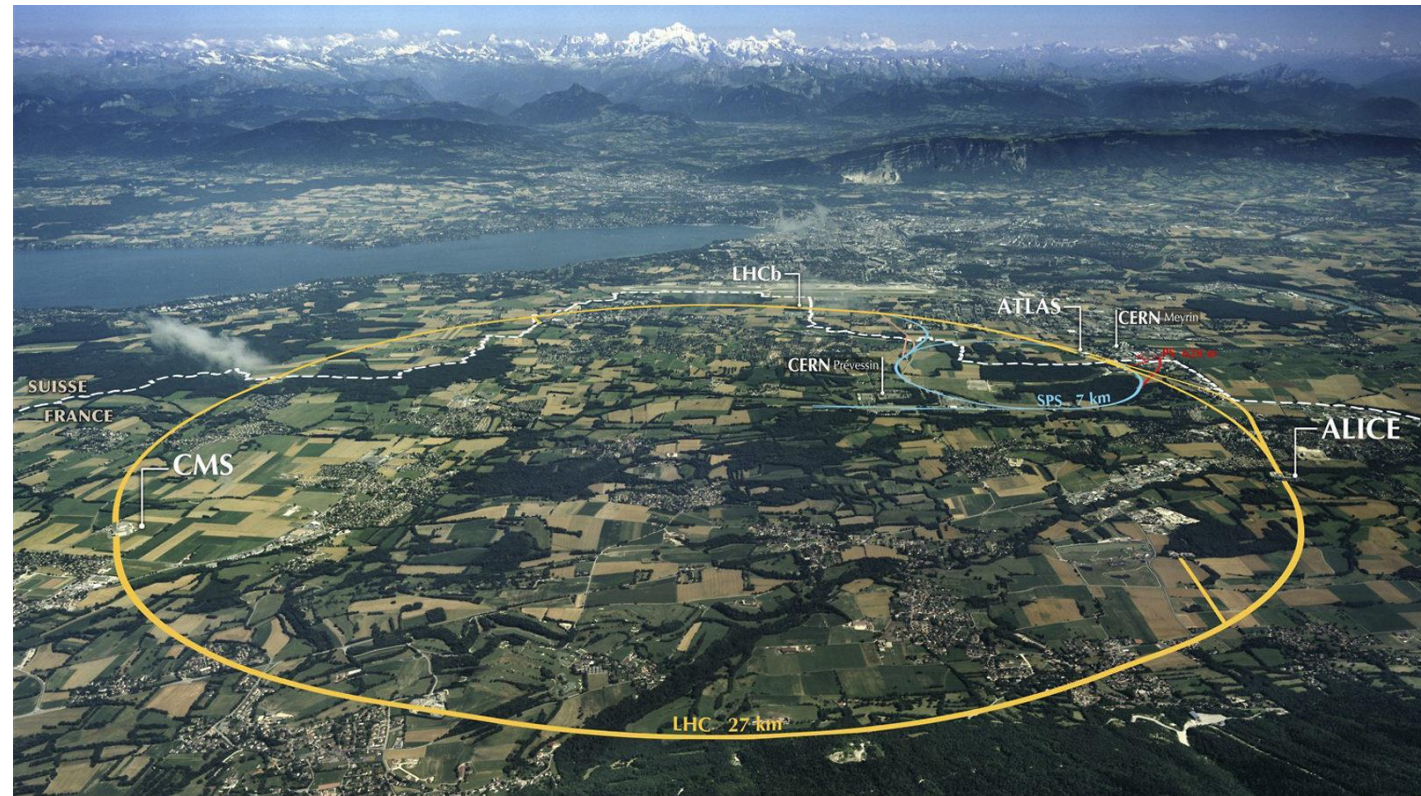
Under the supervision of Dr. Jesse Heilman



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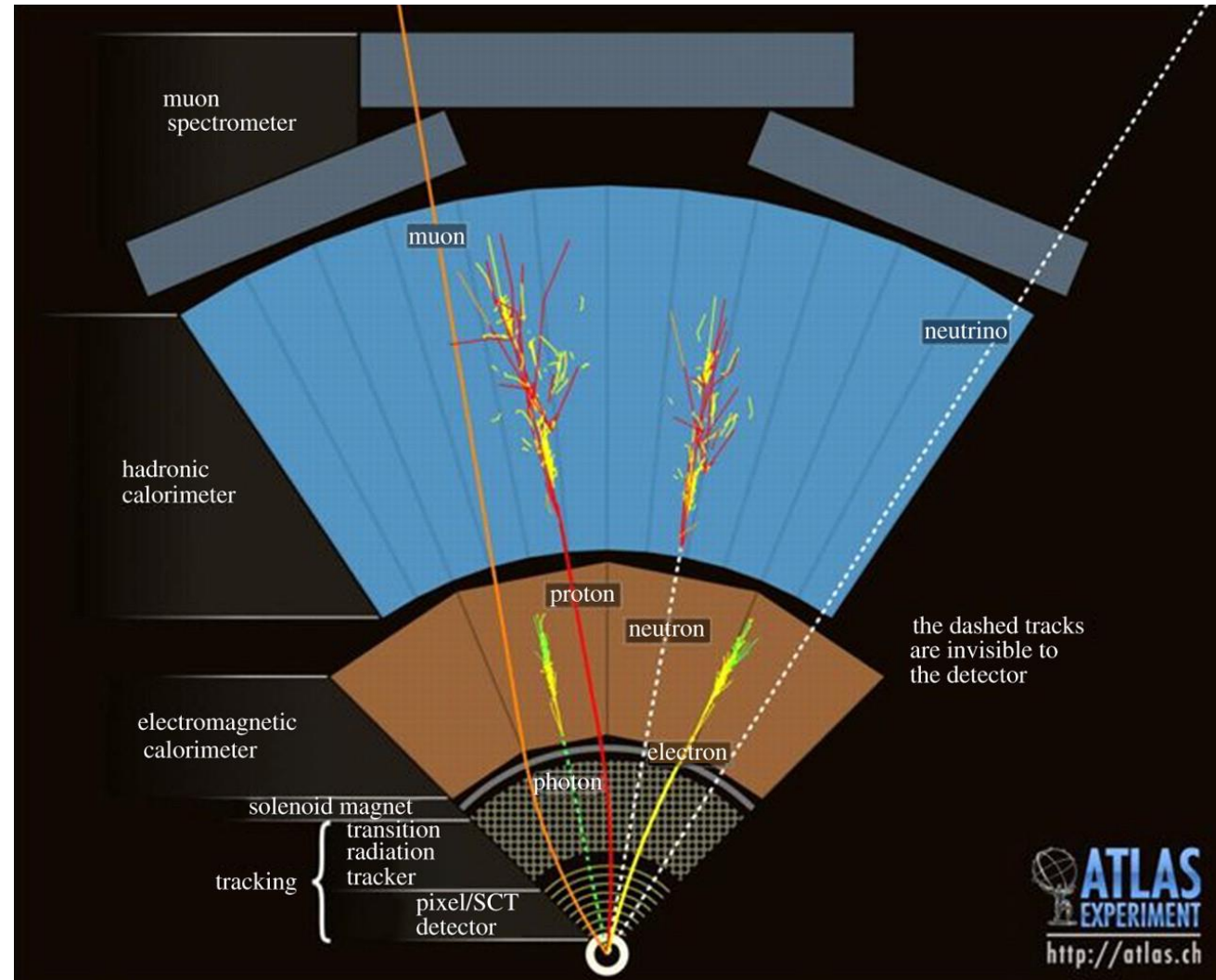
Large Hadron Collider

- Located at CERN
- Worlds Largest particle accelerator
- Can reach 13.6 TeV



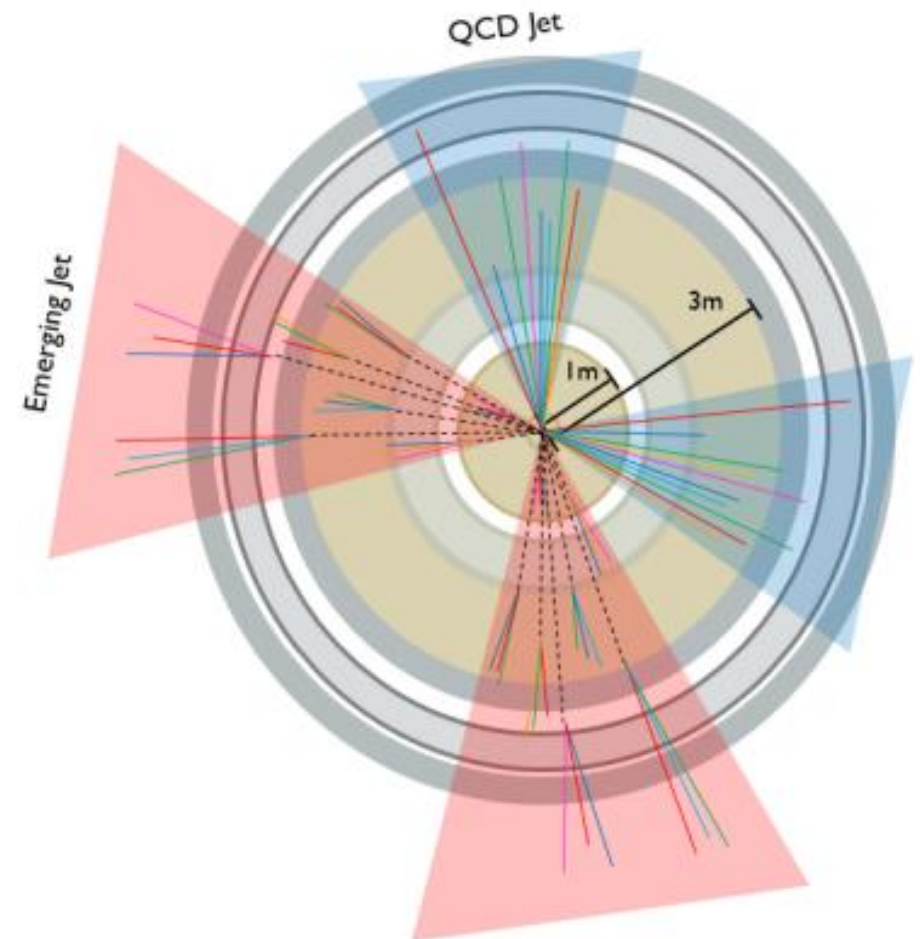
ATLAS Detector

- Largest experiment on the LHC
- Consists of three parts
 - Inner Detector
 - Calorimeter
 - Muon Spectrometer

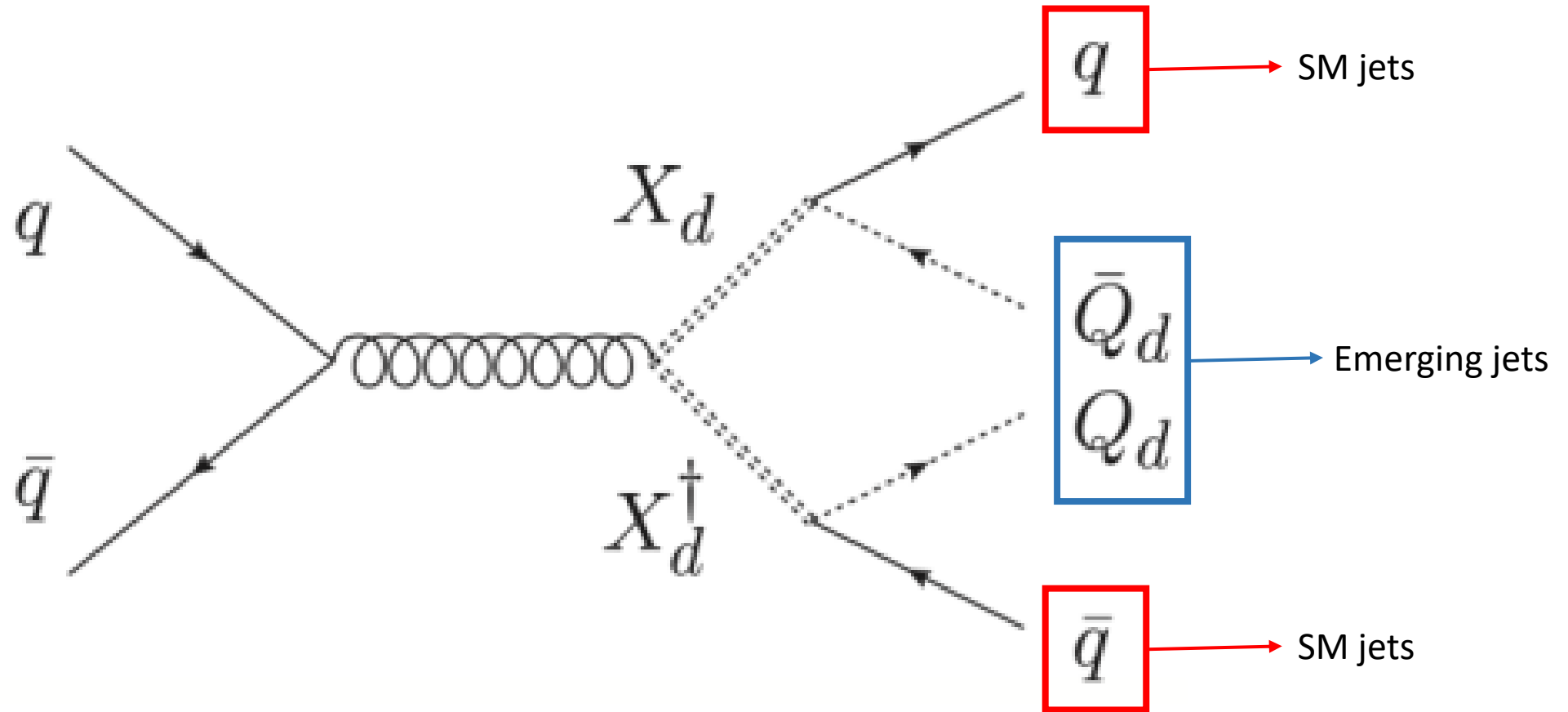


What are Emerging Jets?

- Proposed by Schwaller, Stolarski, and Weiler
- Assumes a QCD-like dark sector in the Hidden Valley
- Dark Mediator allows for creation of dark particles
- For this research
 - Using EJ to find dark QCD
 - Focused on LHC run 3



Creation of EJ



$q \rightarrow$ quark
 $Q_d \rightarrow$ dark quark
 $X_d \rightarrow$ dark mediator

Dark QCD Models & Mediator Mass

- 5 model parameters for Dark QCD
- There are 3 potential mediator masses proposed
- Focused on Model A 600 GeV mediator mass

Model	Λ_d [GeV]	m_{π_d} [GeV]	m_{ρ_d} [GeV]	m_{X_d} [GeV]
A	10	5	20	1400 1000 600
B	4	2	8	1400 1000 600
C	20	10	40	1400 1000 600
D	40	20	80	1400 1000 600
E	1.6	0.8	3.2	1400 1000 600

$m_{X_d} \rightarrow$ dark mediator mass

$m_{\rho_d} \rightarrow$ dark rho mass

$m_{\pi_d} \rightarrow$ dark pion mass

$\Lambda_d \rightarrow$ QCD confinement scale

Dark QCD Models & Mediator Mass

- 5 model parameters for dark particles
- There are 3 potential mediator masses proposed
- Focused on Model A 600 GeV mediator mass

Model	Λ_d [GeV]	m_{π_d} [GeV]	m_{ρ_d} [GeV]	m_{X_d} [GeV]
A	10	5	20	1400
				1000
				600
B	4	2	8	1400
				1000
				600
C	20	10	40	1400
				1000
				600
D	40	20	80	1400
				1000
				600
E	1.6	0.8	3.2	1400
				1000
				600

$m_{X_d} \rightarrow$ dark mediator mass
 $m_{\rho_d} \rightarrow$ dark rho mass
 $m_{\pi_d} \rightarrow$ dark pion mass
 $\Lambda_d \rightarrow$ QCD confinement scale

Simulating Emerging Jets

- Simulated events through ATLAS reconstruction
- Composition of models produced by study:
 - Truth Jet
 - Truth level
 - SM Particle Jet
 - Dark Jet
 - Truth level
 - Dark particle Jet
 - Reconstructed Jet
 - Detector read out level
 - Jets reconstructed and matched to a truth level jet

Dark Matched:

$$X_d \rightarrow Q_d \rightarrow \text{Dark} \rightarrow \text{Truth} \rightarrow \text{Reco}$$

Not Dark Matched:

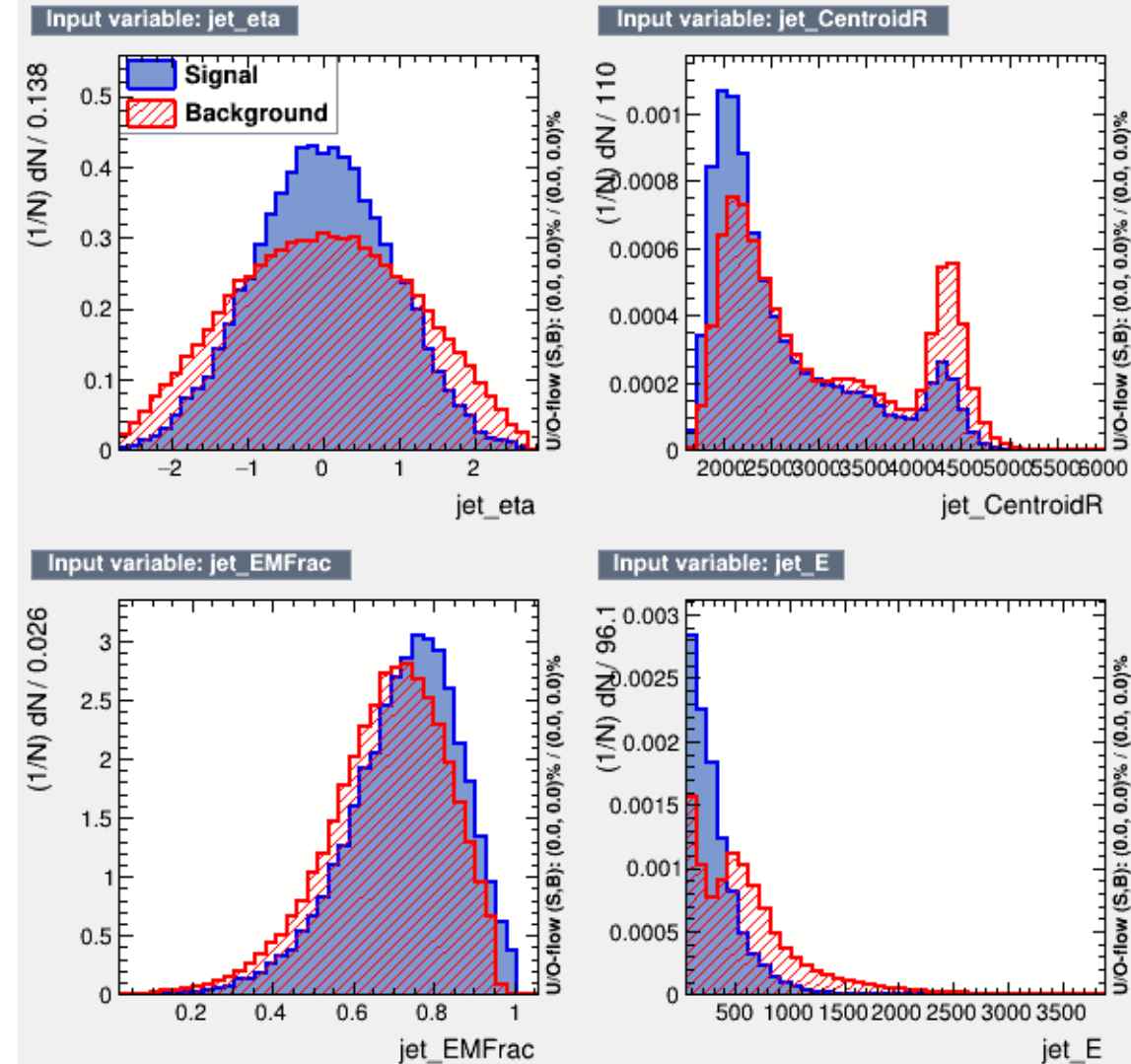
$$X_d \rightarrow q \rightarrow \text{Truth} \rightarrow \text{Reco}$$

Training Methods

- Machine Learning using ROOT's TMVA
- Signal: Simulated dark matched and truth matched reco jets
- Background: Sample of Simulated QCD
- Boosted Decision Tree (BDT)
 - Used previously for examination for run 2
- Multi Layer Perceptron (MLP)
 - Basic and effective Neural Net
- Dense Neural Network (DNN)
 - More advanced MLP

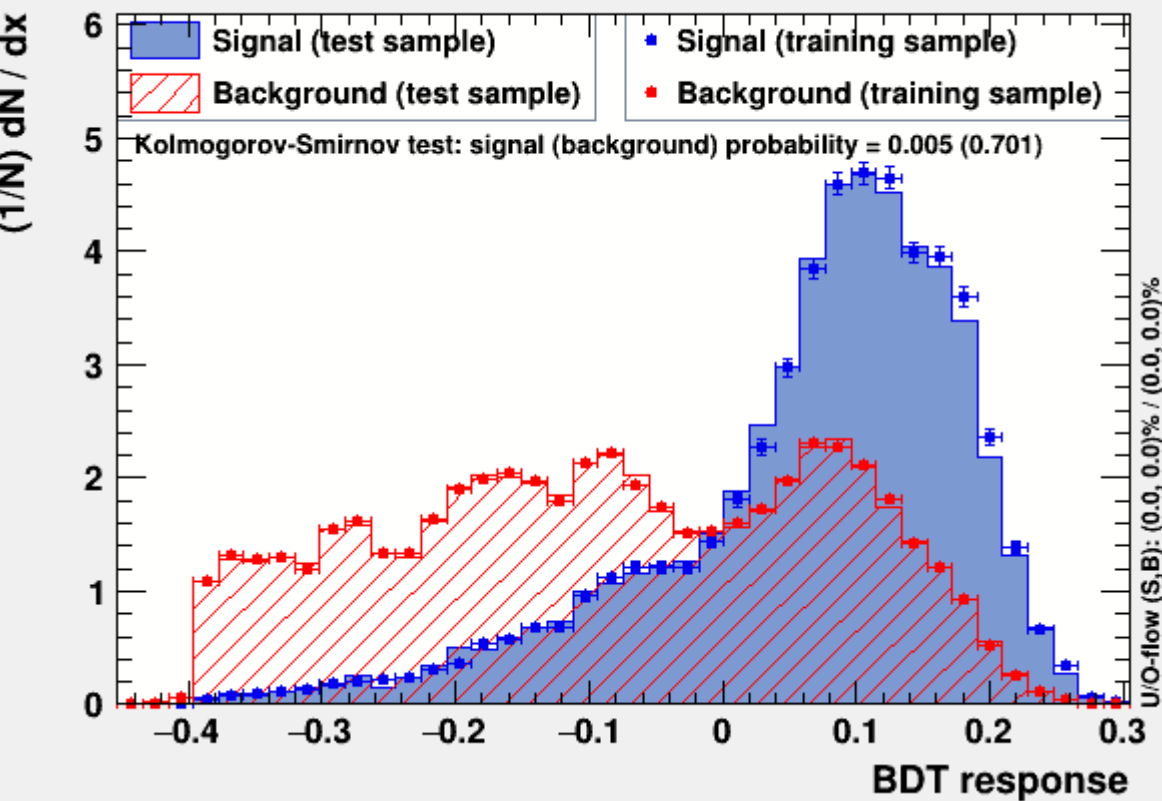
Variables

- Variables used:
 - Eta
 - CentroidR
 - EMFrac
 - E
- Plans to include other variables in the future

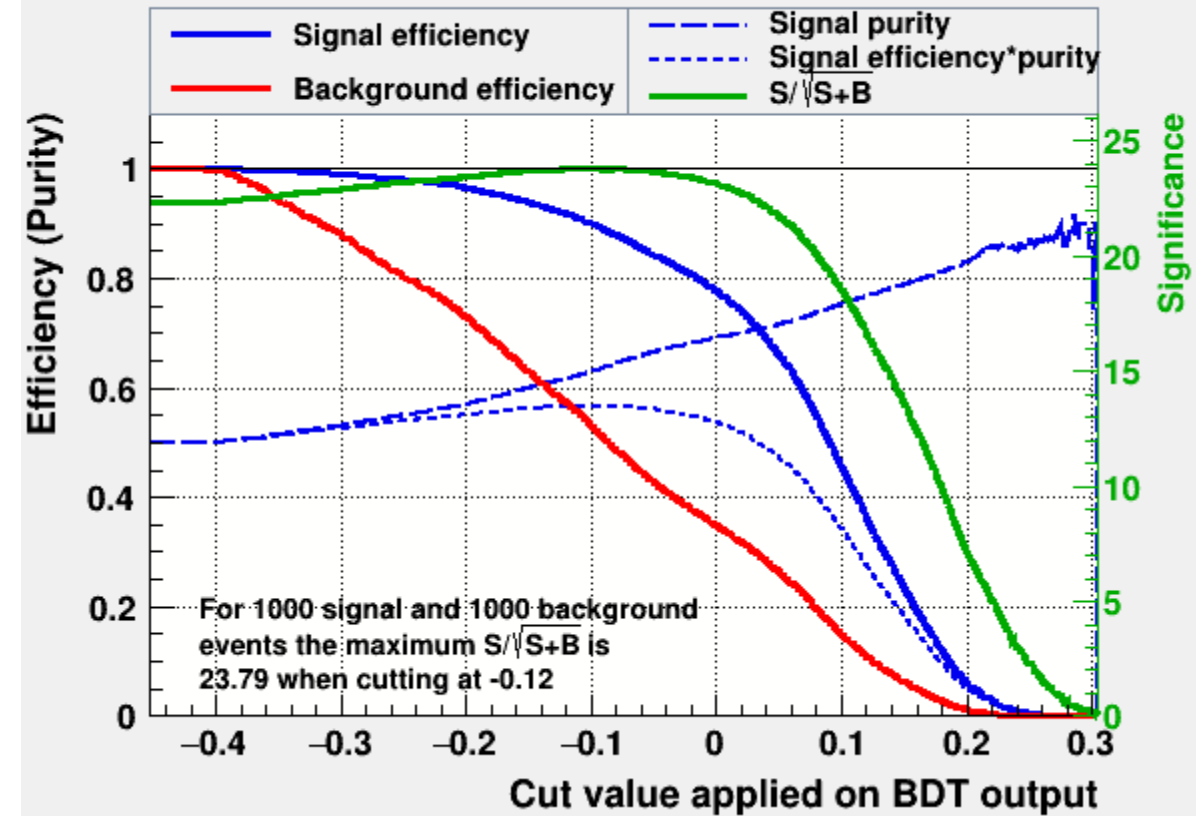


Boosted Decision Tree

TMVA overtraining check for classifier: BDT

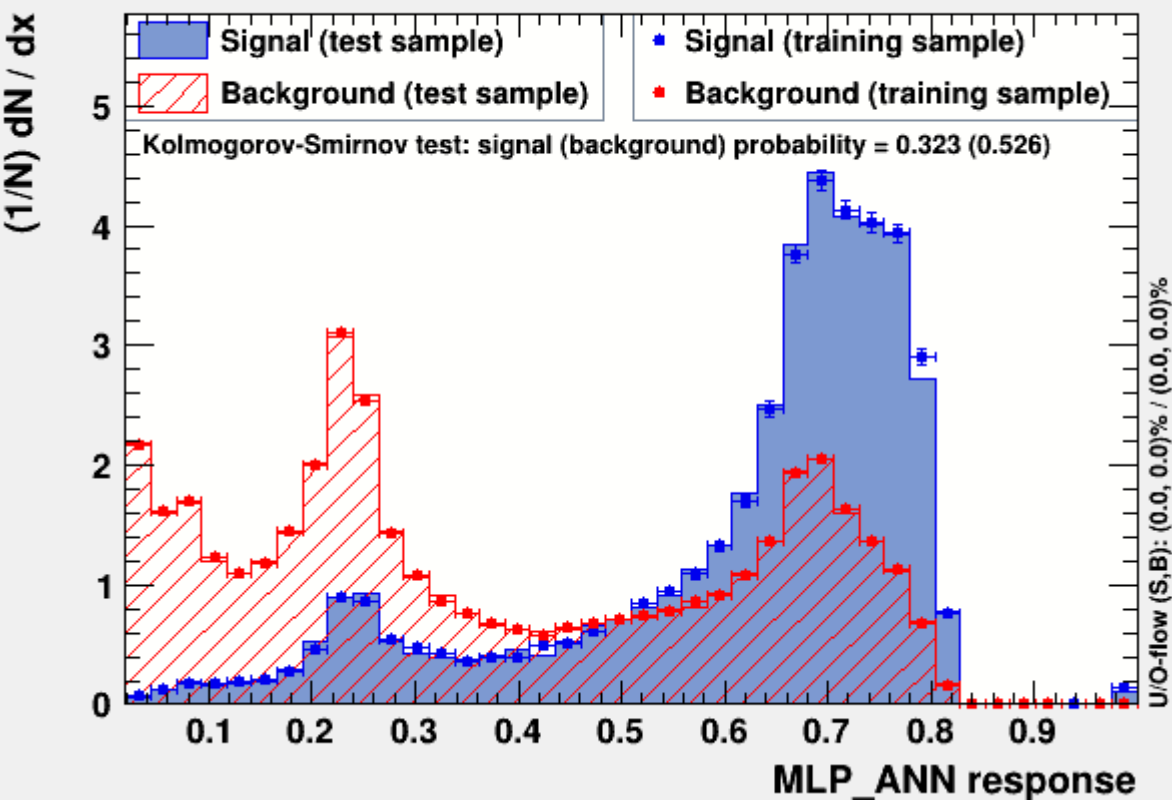


Cut efficiencies and optimal cut value

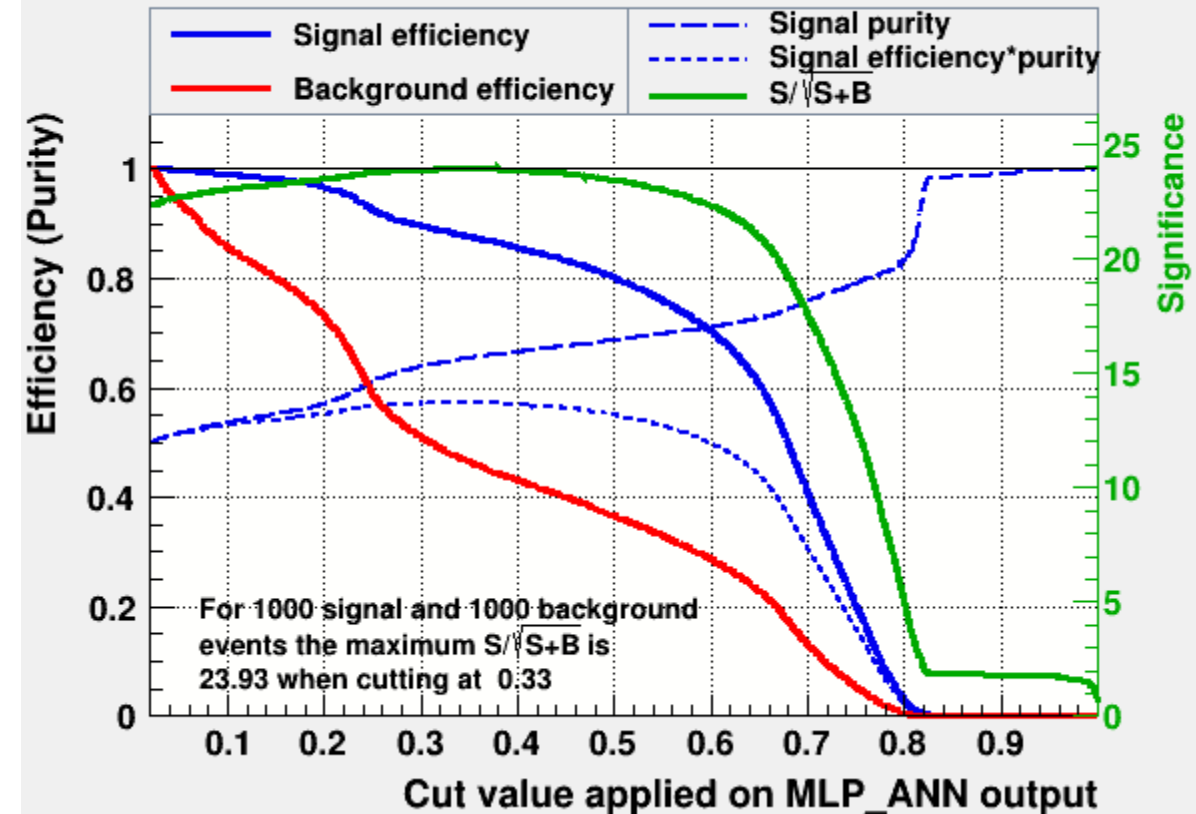


Multi Layer Perceptron - Tanh

TMVA overtraining check for classifier: MLP_ANN



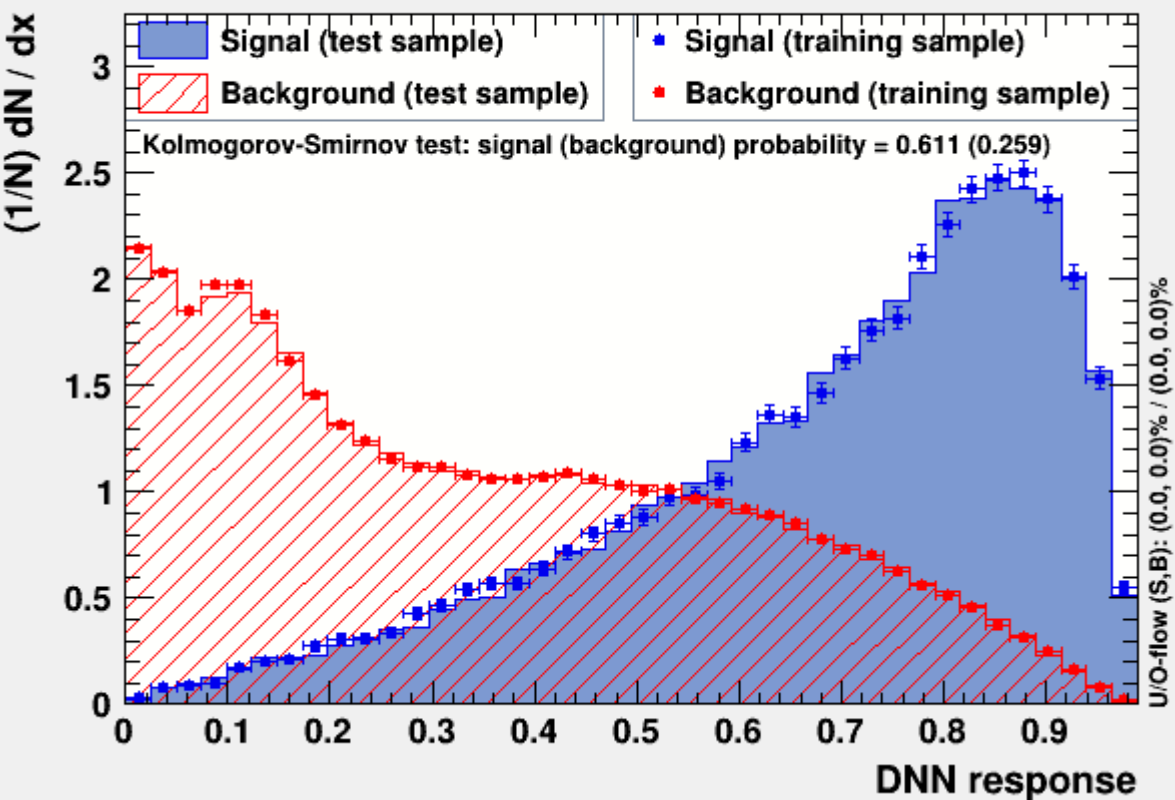
Cut efficiencies and optimal cut value



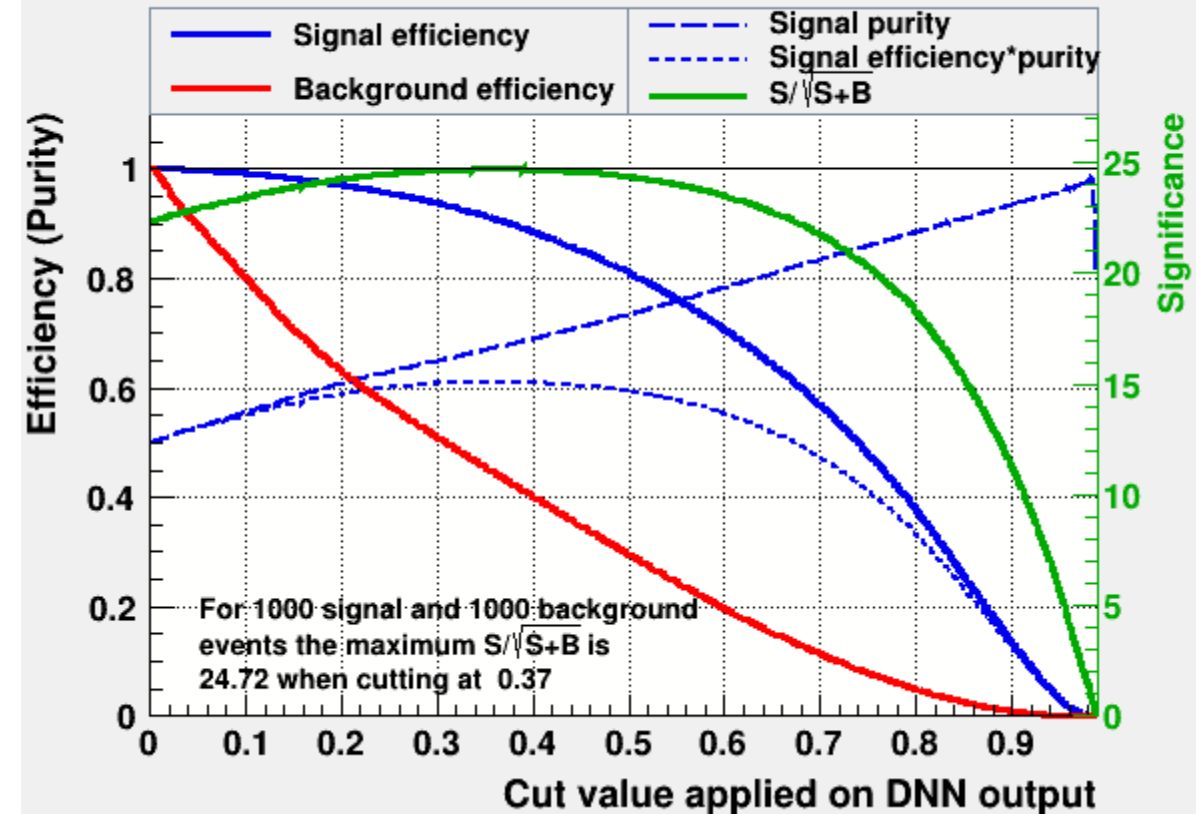
- Activation function shown: Tanh
- Tested also using Sigmoid and ReLU

Dense Neural Network - ReLU

TMVA overtraining check for classifier: DNN



Cut efficiencies and optimal cut value



- Activation function shown: ReLU
- Tested also using Sigmoid and Tanh

Next Steps

- Promising results for classification
- Research will be continued into honors project
 - Check Methods with Different Mediator Masses
 - Check Methods with expanded QCD background
 - Expand variables used in analysis
 - Implement Classifier on events

Any questions?

References

- [1] B. Death, “Jet comparison, trigger, and sensitivity studies of Dark Sector Emerging Jet MC Models.”
- [2] I. Ramirez-Berend, “Implementation of machine learning techniques in the search for emerging jets using the Atlas Run II Dataset.”
- [3] P. Schwaller, D. Stolarski, and A. Weiler, “Emerging jets,” *Journal of High Energy Physics*, vol. 2015, no. 5, 2015.

Backup

Dark pion lifetimes associated with Dark Mediator

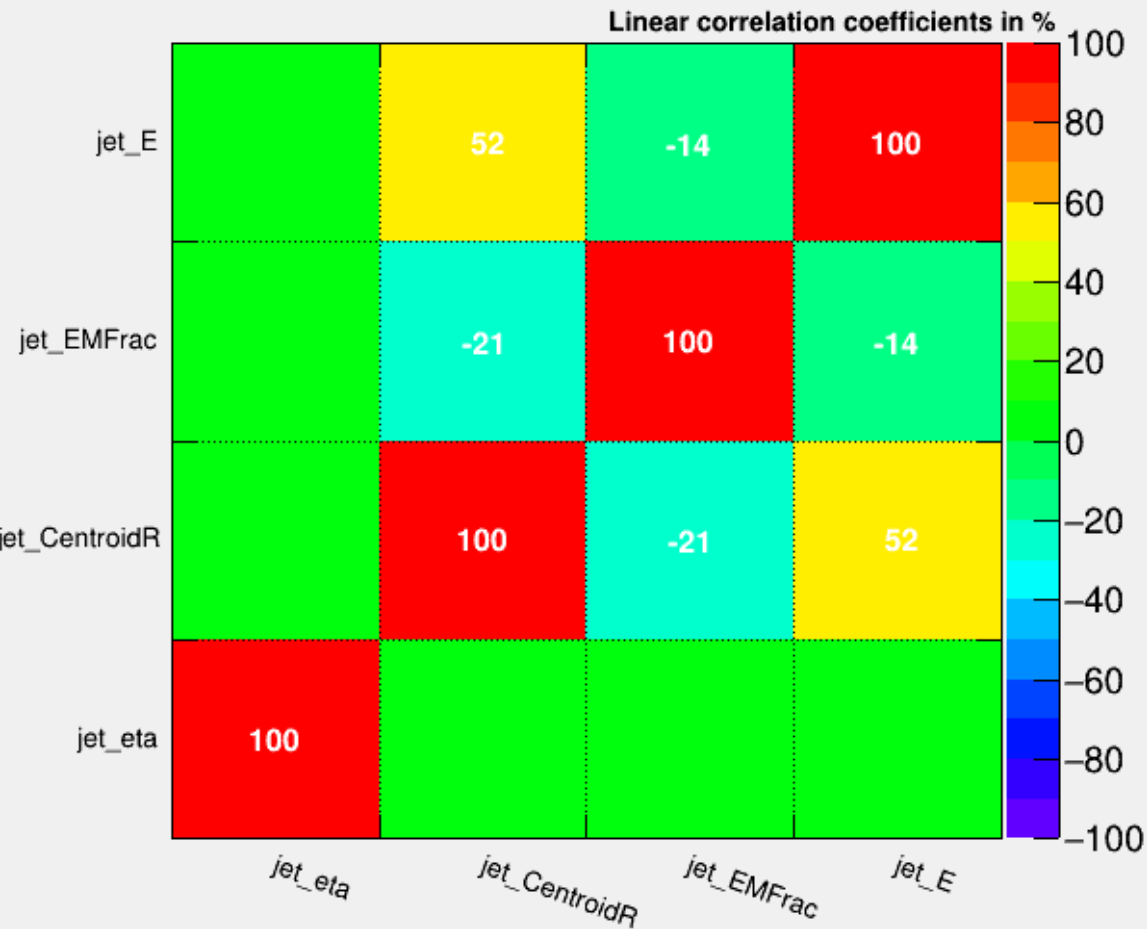
χ_d [GeV]	$c\tau_{\pi_d}$ [mm]
600	0.5, 1, 2, 20, 150, 300
1000	1, 2, 5, 75, 150, 300
1400	2, 5, 20, 75, 150, 300

Activation Functions

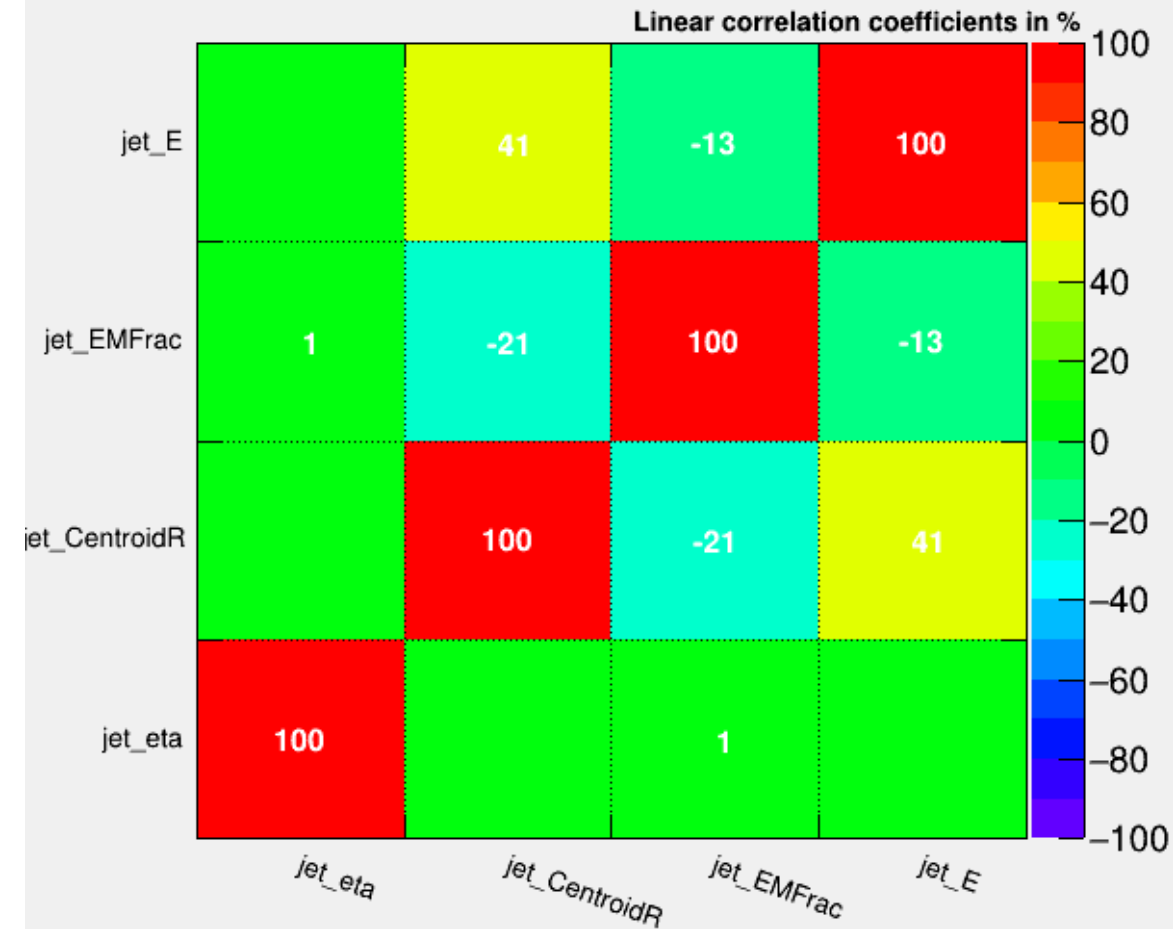
- ReLU $\rightarrow \begin{cases} x & \text{if } x \geq 0 \\ 0 & \text{otherwise} \end{cases}$
- Tanh $\rightarrow \tanh(x)$
- Sigmoid $\rightarrow \frac{1}{1+e^{-x}}$

Correlation Matrix

Correlation Matrix (background)



Correlation Matrix (signal)



BDT

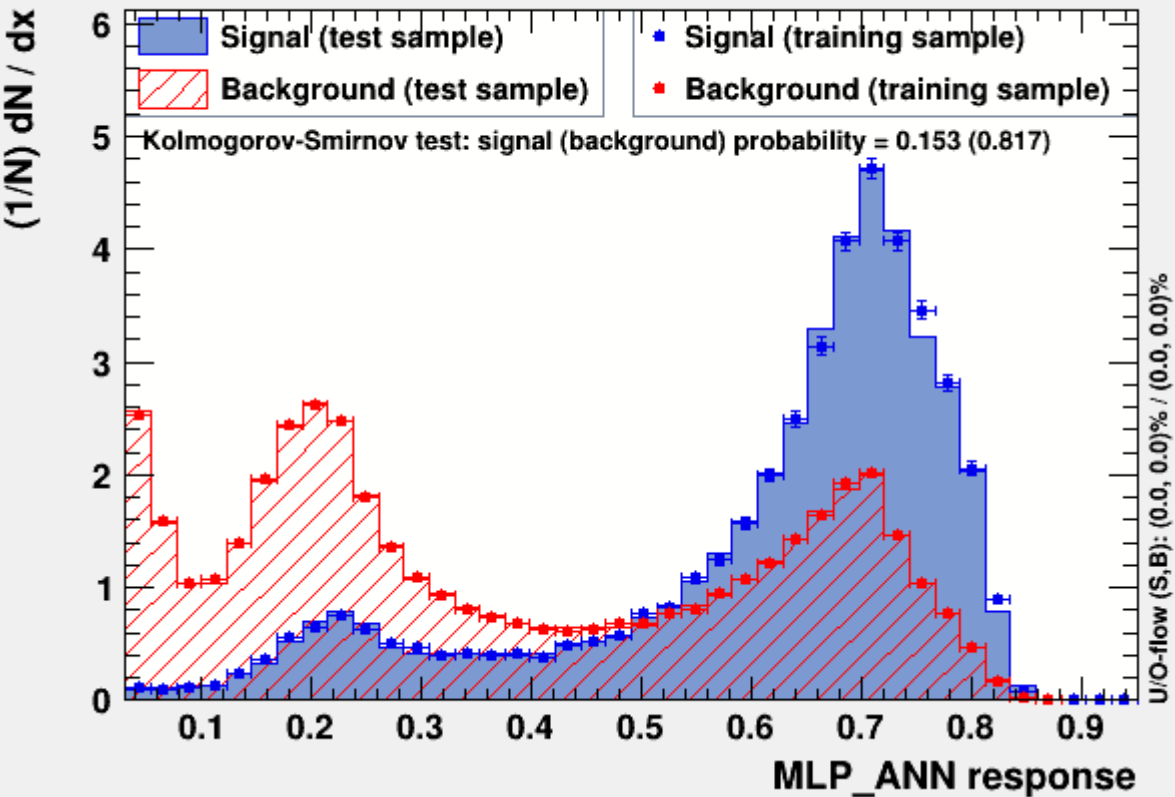
- Using TMVA's kBDT method
- Conditions
 - 800 trees
 - Min node size: 5%
 - Max tree depth: 3
 - Using Ada boost with boost beta of 0.5
 - Cross entropy separation type
 - 20 cuts

MLP

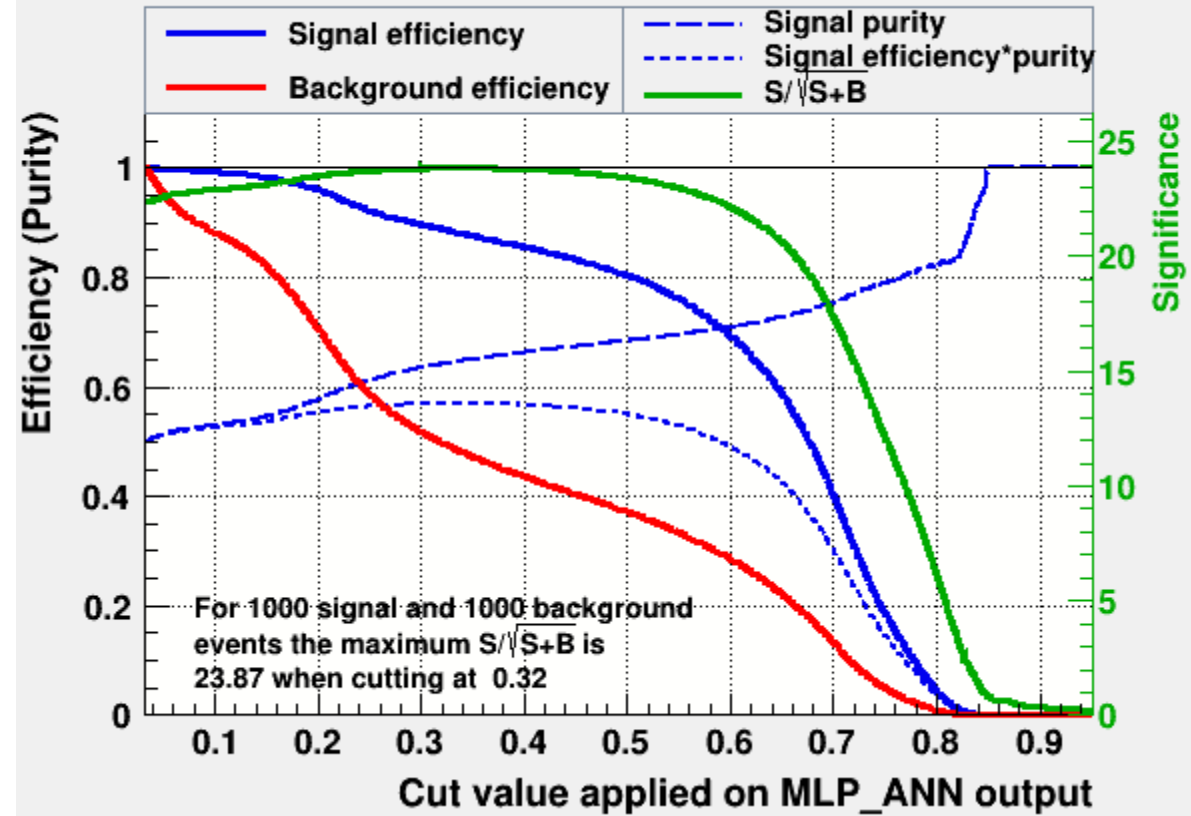
- Using TMVA's kMLP method
- Conditions
 - Normalized
 - 1000 cycles
 - 2 layers of 4 and 5 neurons
 - Test rate of 10
 - Using useregulator = True

MLP - Sigmoid

TMVA overtraining check for classifier: MLP_ANN

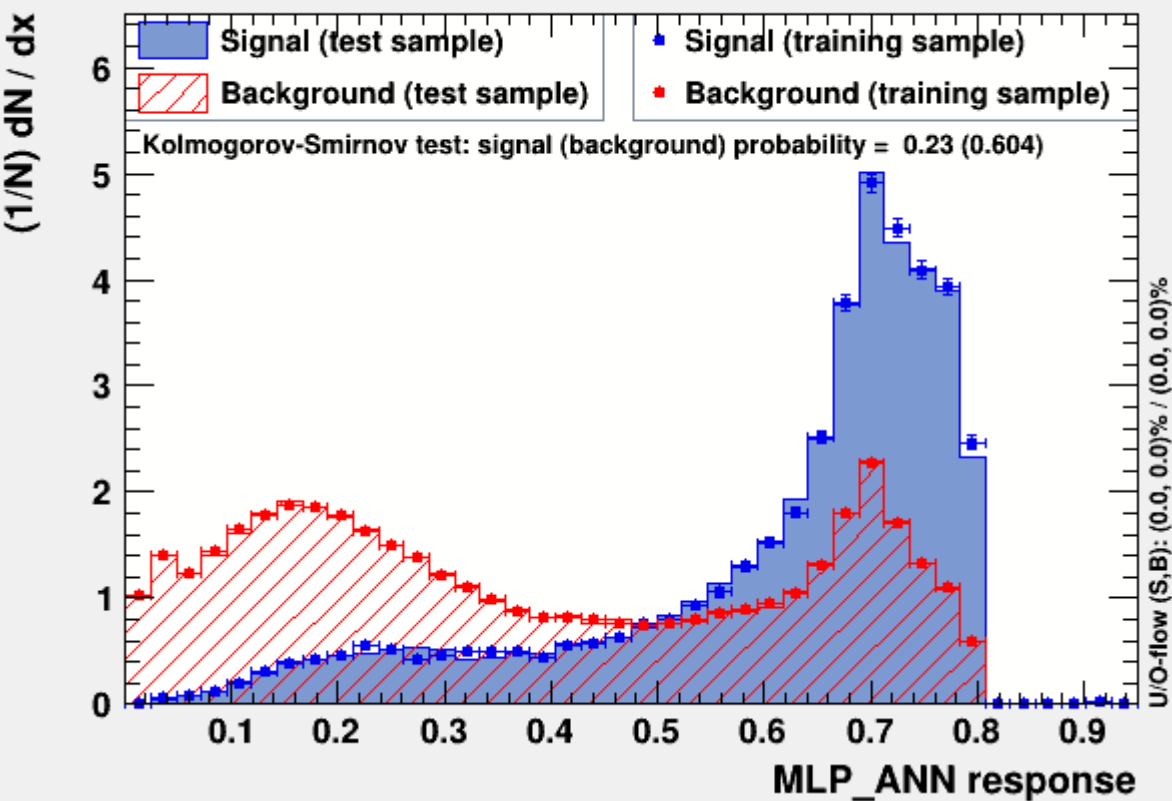


Cut efficiencies and optimal cut value

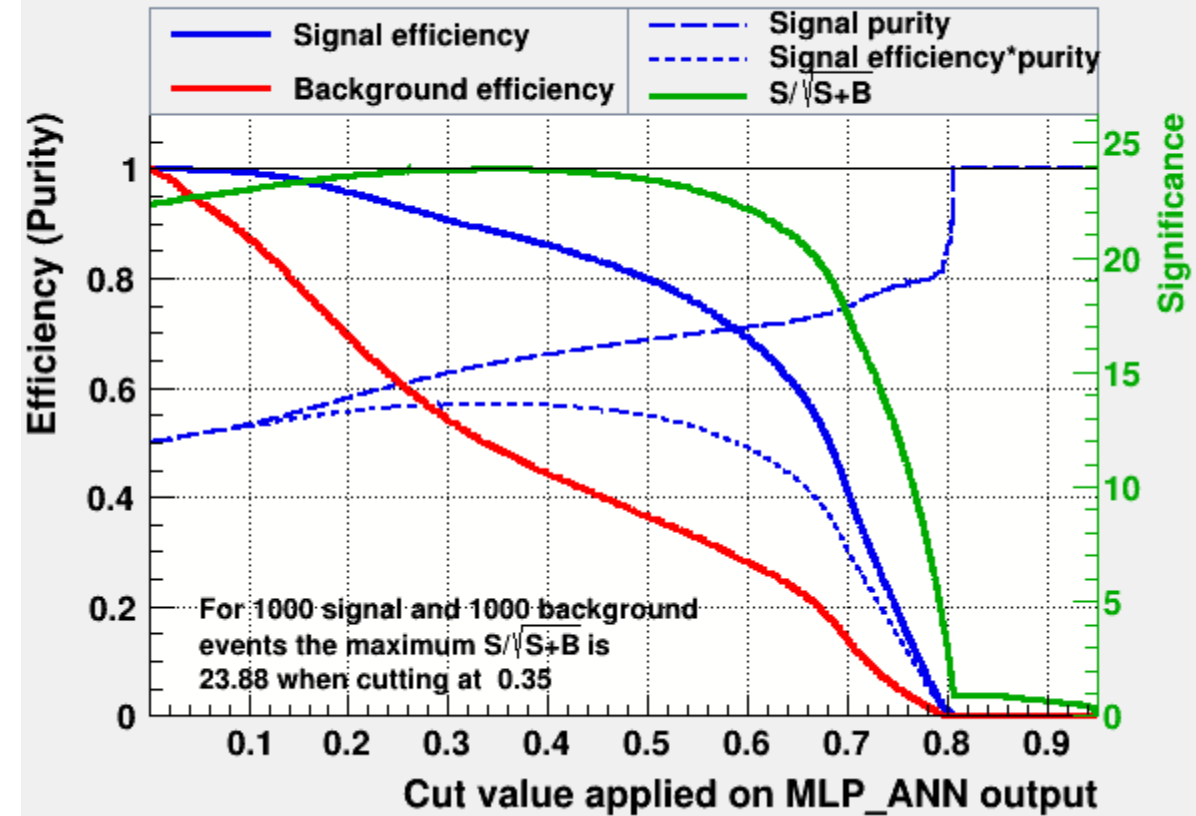


MLP - ReLU

TMVA overtraining check for classifier: MLP_ANN



Cut efficiencies and optimal cut value

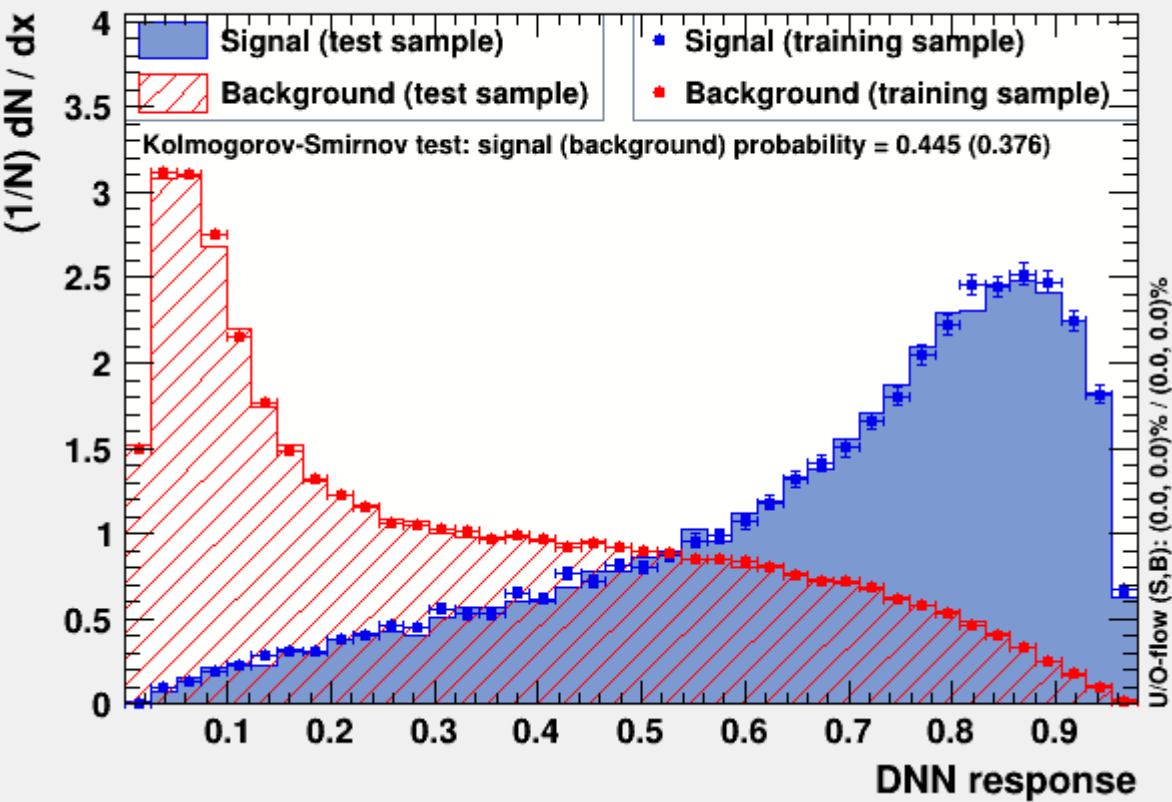


DNN

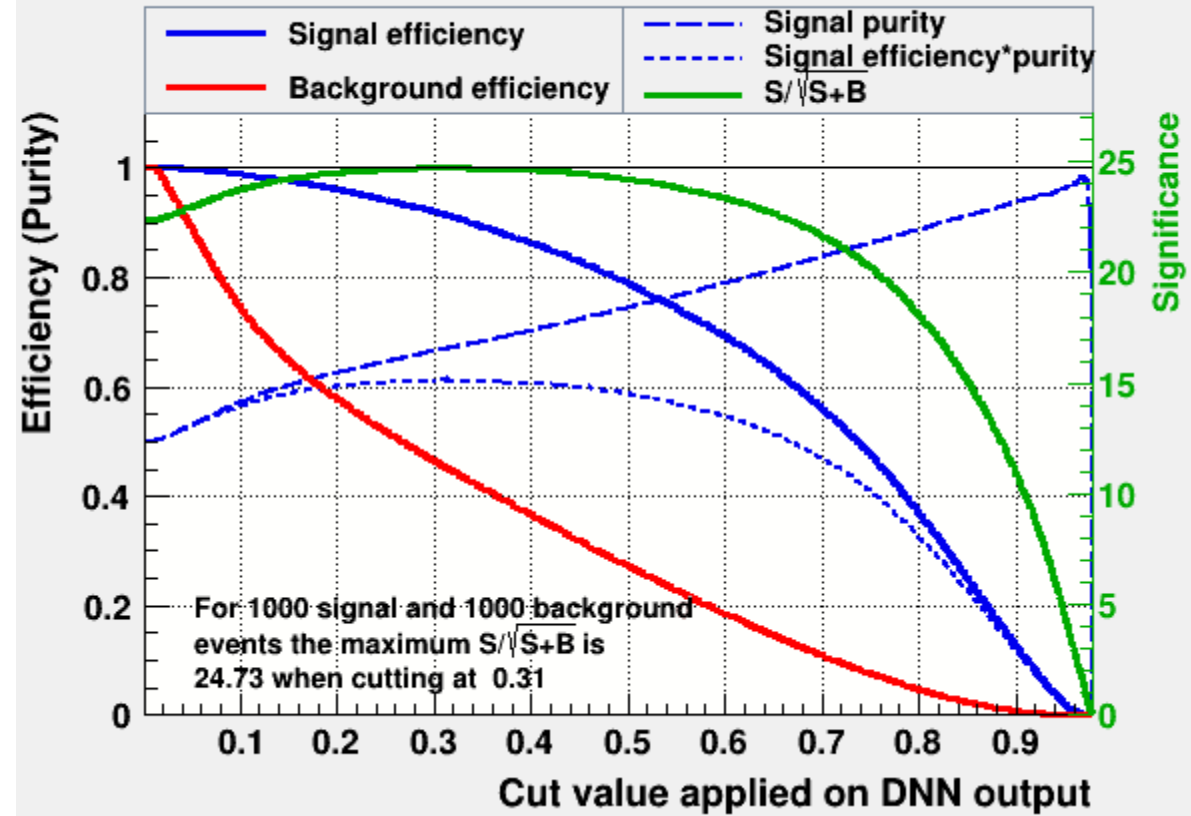
- Using TMVA's kDL method
- Conditions
 - Error strategy of cross entropy
 - Uniform weight initialization
 - 3 layers of 80 neurons
 - Max epoch of 1000

MLP - Sigmoid

TMVA overtraining check for classifier: DNN

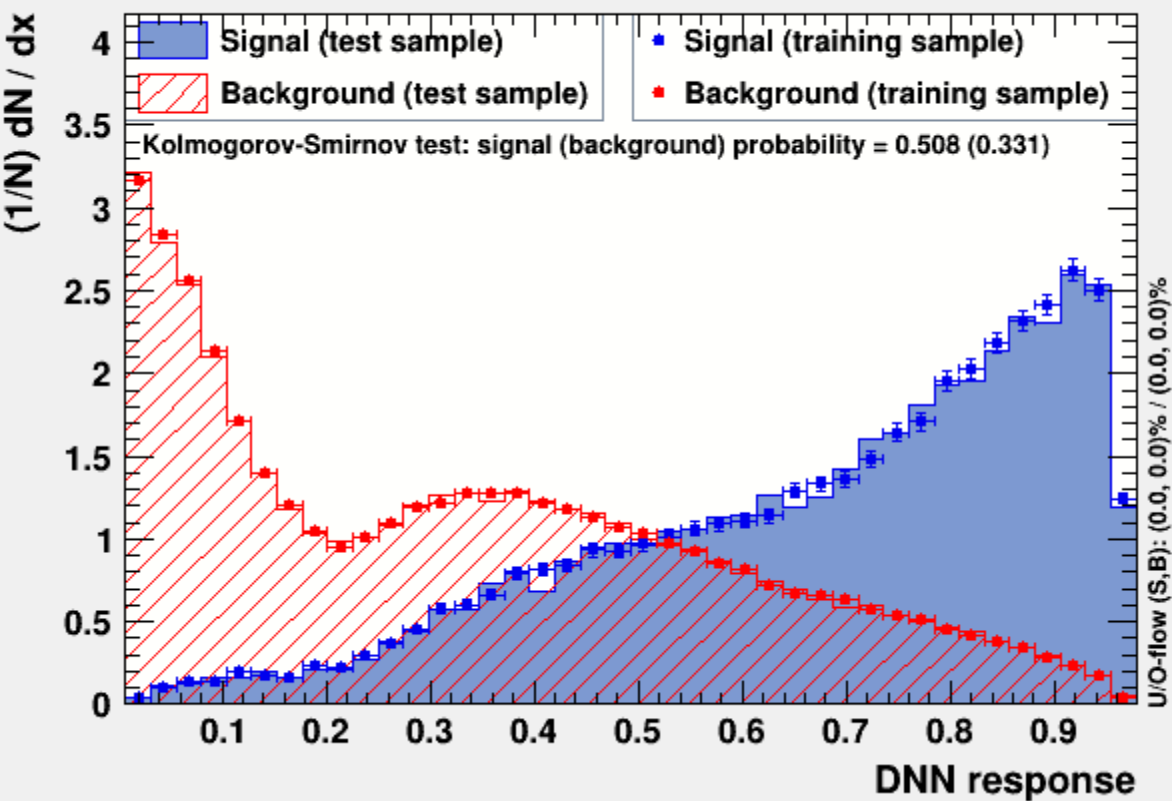


Cut efficiencies and optimal cut value

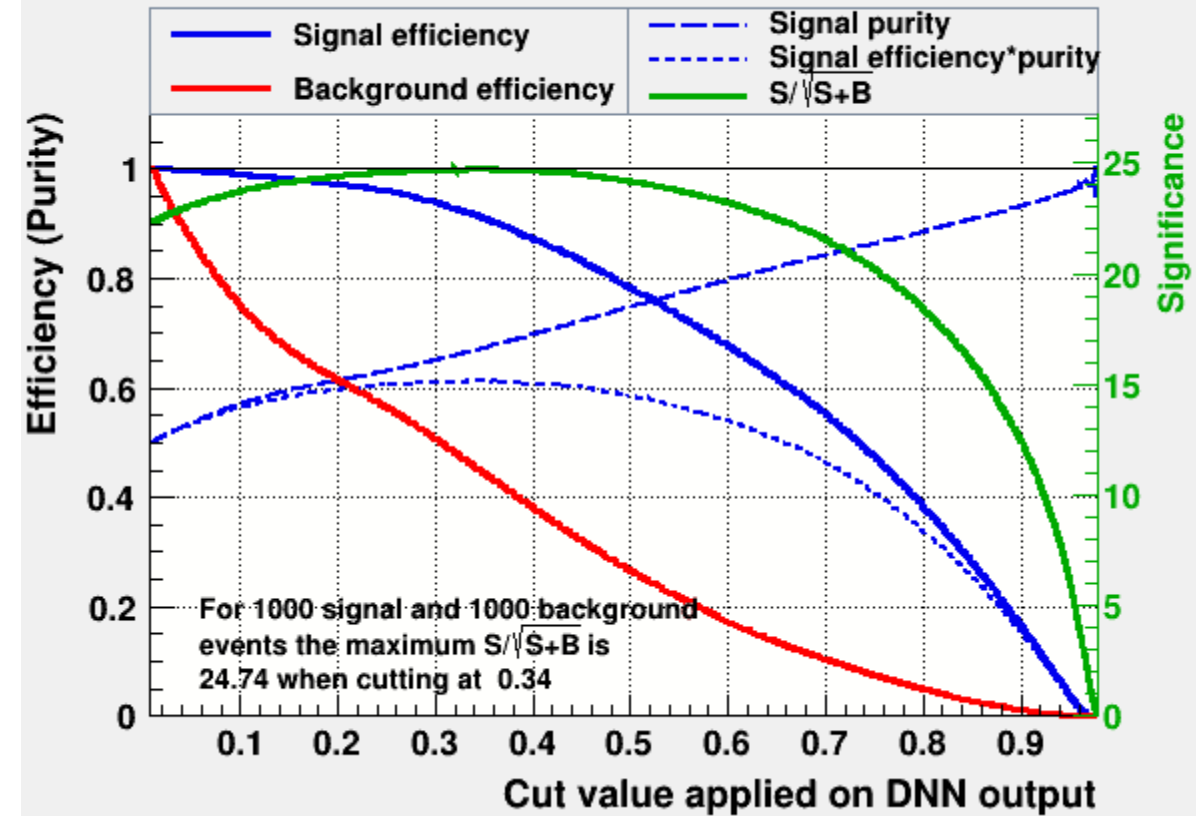


MLP - Tanh

TMVA overtraining check for classifier: DNN



Cut efficiencies and optimal cut value



Cross Entropy Equation

- Defined by
 - $-p \cdot \ln(p) - (1 - p) \cdot \ln(1 - p)$
 - Where p is purity (ranges from 0.5 to 0)