Top Quark Production with an Associated Z Boson

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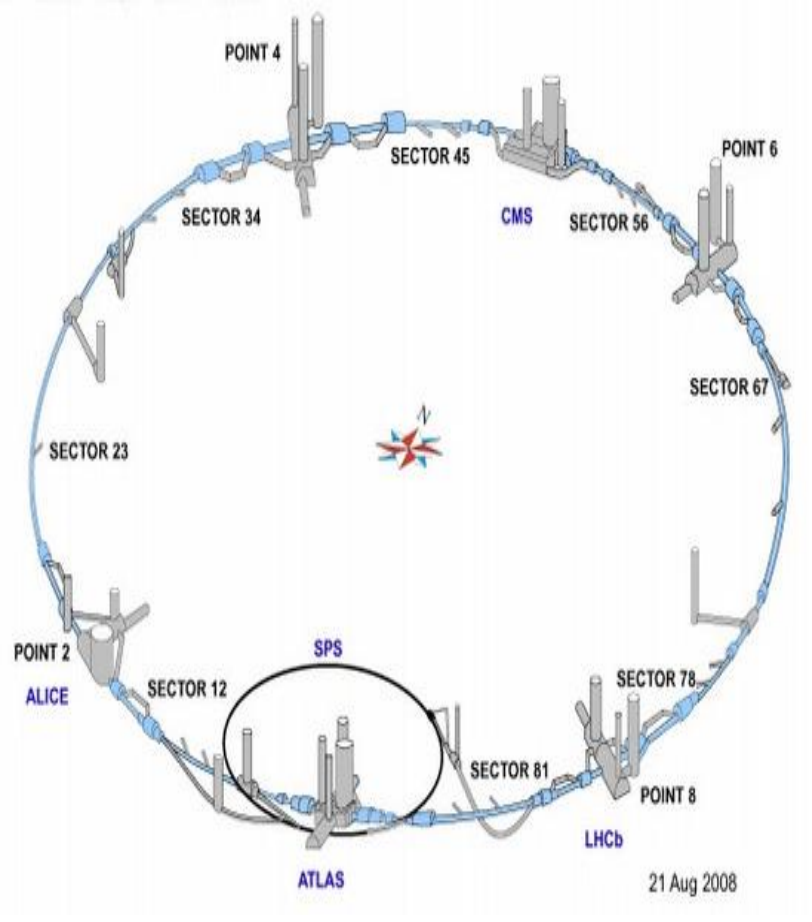
Top quark production with an associated Z boson (tZ) is one of only a few possible methods of single *t* production

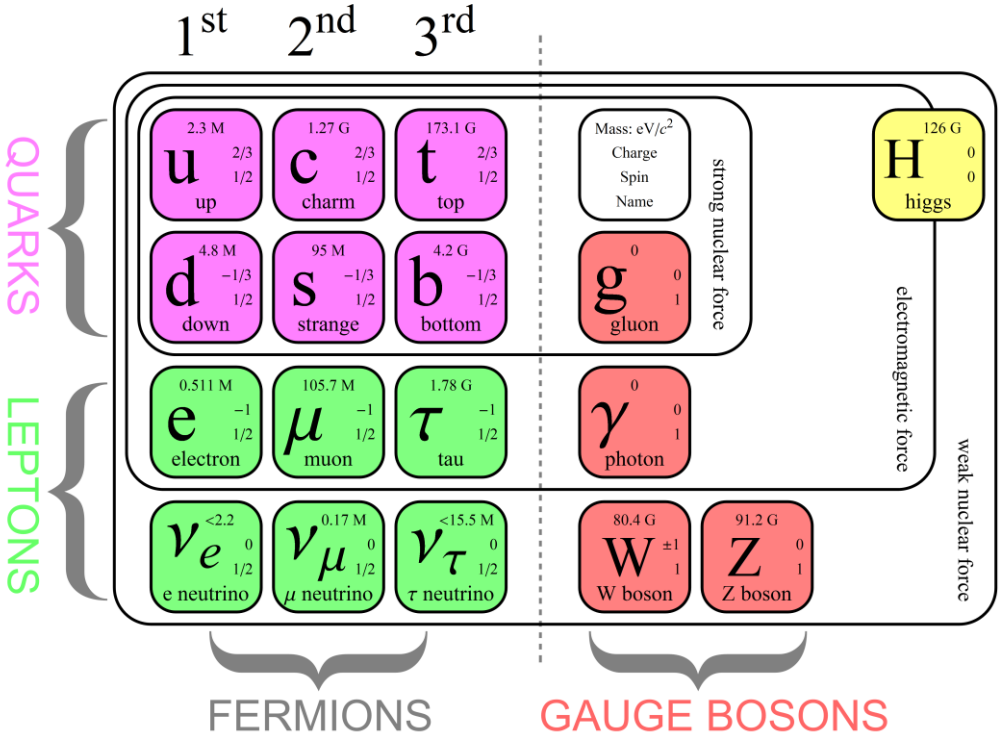
- Top quarks generally do not appear alone
- Lone top quarks were theorized to appear with a W boson partner (tW production)
- The next step was the search for lone top quarks with an associated Z boson (tZ)



The process of top quark production with an associated Z boson is expected but has not been observed

- Components –
  - Bottom quark
  - Some other quark (q)
- Products –
  - Top quark
  - Resultant quark (q')
  - Z boson

- Detection is done using final decay products
  - The trilepton state of decay is the current signal target



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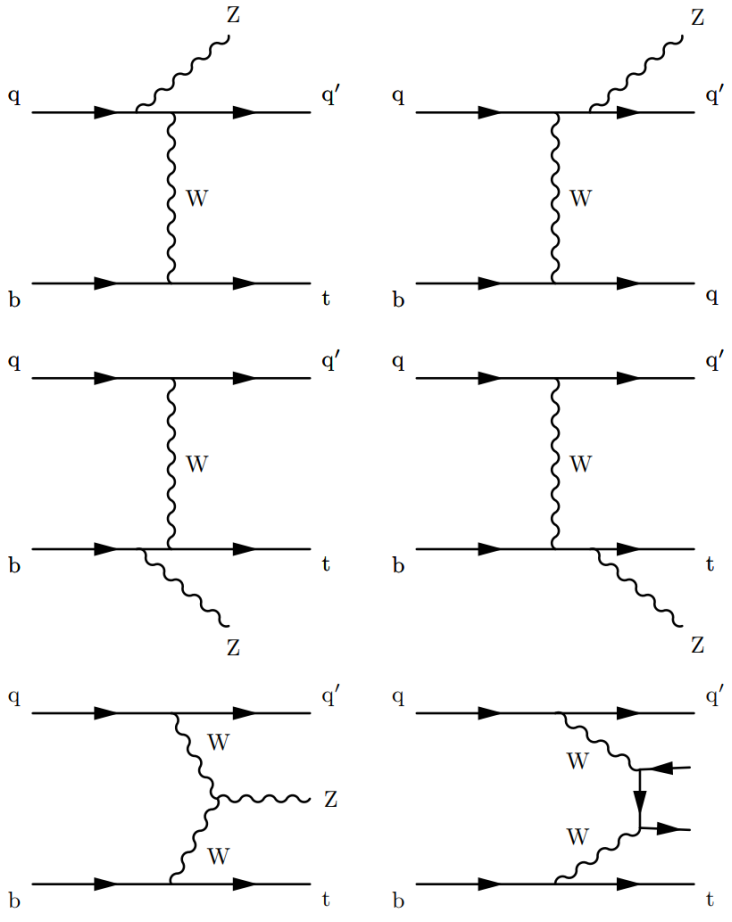

Analysis is done using a neural network to locate traces of decay products in collision data

Detections occur by searching for specific resulting states

- Hadronic
- Single Lepton
- Dilepton
- Trilepton

leptonic	hadronic
$W^+ \rightarrow l^+\nu$	$W^+ \rightarrow q\bar{q}$
$W^- \rightarrow l^-\bar{\nu}$	$W^- \rightarrow q\bar{q}$

hadronic	leptonic	
	visible	invisible
$Z^\circ \rightarrow q\bar{q}$	$Z^\circ \rightarrow e^+e^-$	$Z^\circ \rightarrow \nu\bar{\nu}$
	$Z^\circ \rightarrow \mu^+\mu^-$	
	$Z^\circ \rightarrow \tau^+\tau^-$	

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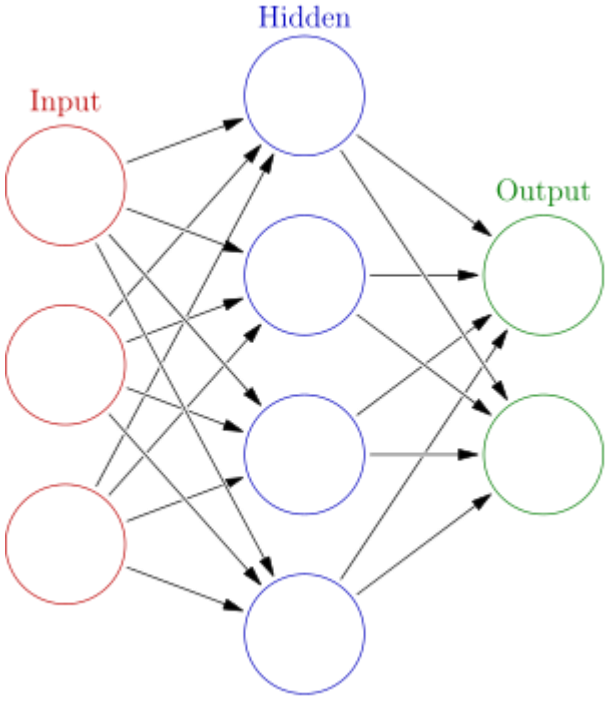
The use of machine aids in the analysis and discovery process of the tZq interaction

- A phenomena is not considered discovered until it has a statistical significance of 5 sigma
- In order to increase significance, extremely large amounts of data are required $\left(\frac{s}{\sqrt{b}}\right)$
- To expedite the process, deep learning techniques are used to find more positive events in the data



Different machine learning approaches are used to analyze data, and both are trained using Monte Carlo samples

- Artificial Neural Network- A network that uses interconnected “neurons” to analyze data
  - Neurobayes, which uses Bayesian statistics

- Decision Tree- Uses a constructed decision tree to map observations (inputs) to a value
  - Toolkit for Multivariate Data Analysis (TMVA)

The framework is trained to use the trilepton signal to discriminate from background readings

Network Training

- Take only cases with trilepton products of *eee, μμμ, eμμ,* or *eeμ*
- Network observes correlation between variables and occurrence of trilepton state
- Network can recognize probability of a tZq interaction within a dataset

Variable	Significance(σ)	Definition
η(j)	18.9	Untagged jet η
p_T(j)	18.6	Untagged jet p_T
m_t	15.2	Reconstructed top-quark mass
$p_T(tZt)$	10.9	The tZq system p_T
$p_T(\ell^W)$	7.0	p_T of the lepton coming from the W boson decay
ΔR(j, Z)	6.3	ΔR between untagged jet and Z boson
$m_T(\ell, E_T^{miss})$	4.6	Transverse mass of W-boson
$\eta(\ell^W)$	3.5	η of the lepton coming from the W-boson decay
$p_T(t)$	3.3	Reconstructed top quark p_T
$p_T(b)$	3.1	Tagged jet p_T
$\Delta\phi(t, Z)$	2.5	ΔR between the reconstructed top quark and Z boson
$m(\ell\ell)$	2.5	Reconstructed Z-boson mass
η(Z)	2.0	Reconstructed Z-boson η

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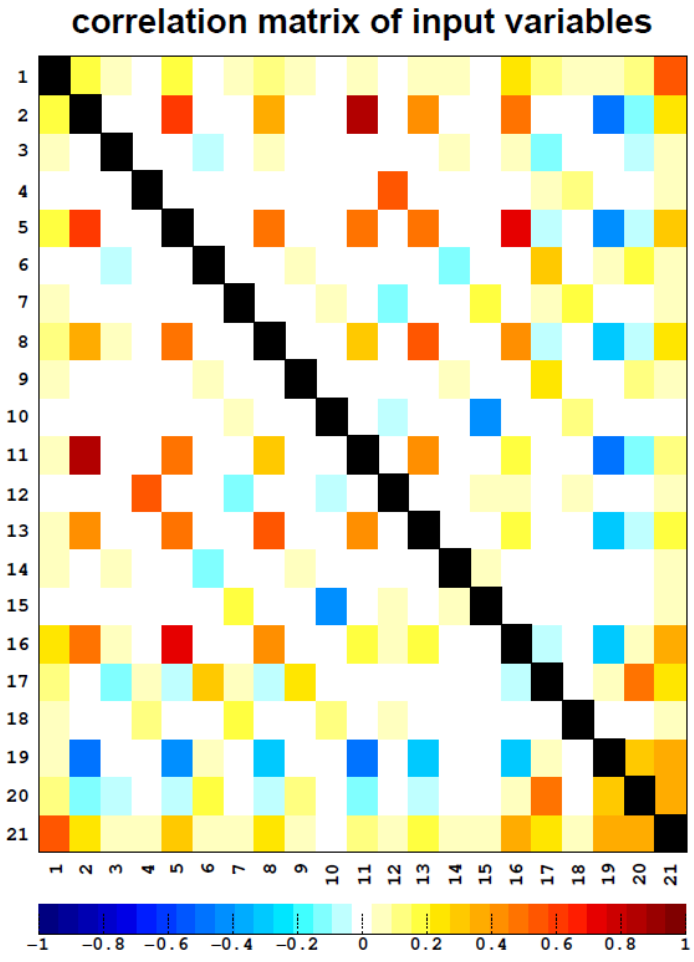
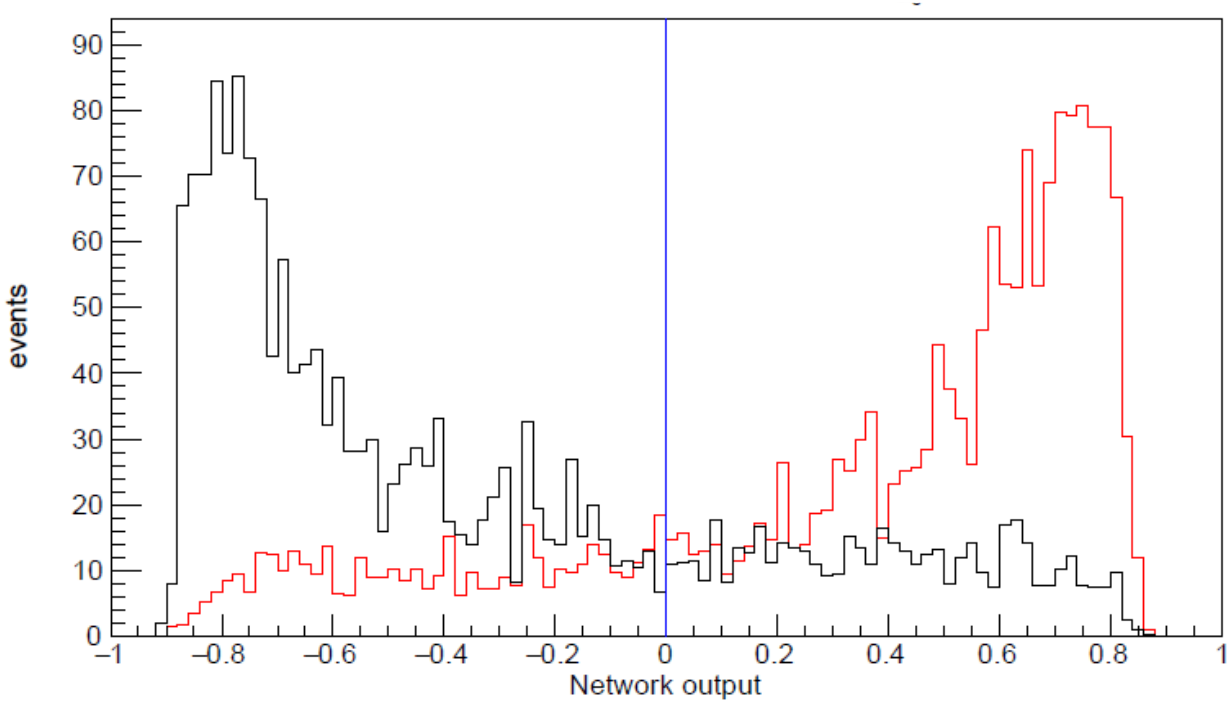


The basic function of the BDT and ANN is to separate signal events from background events as much as possible

- Machine learning attempts to separate signal (events of interest) from background (noise)
- Large separation allows analysis of a set with confidence that limited data is background
- Measured using “signal efficiency” and “background rejection”



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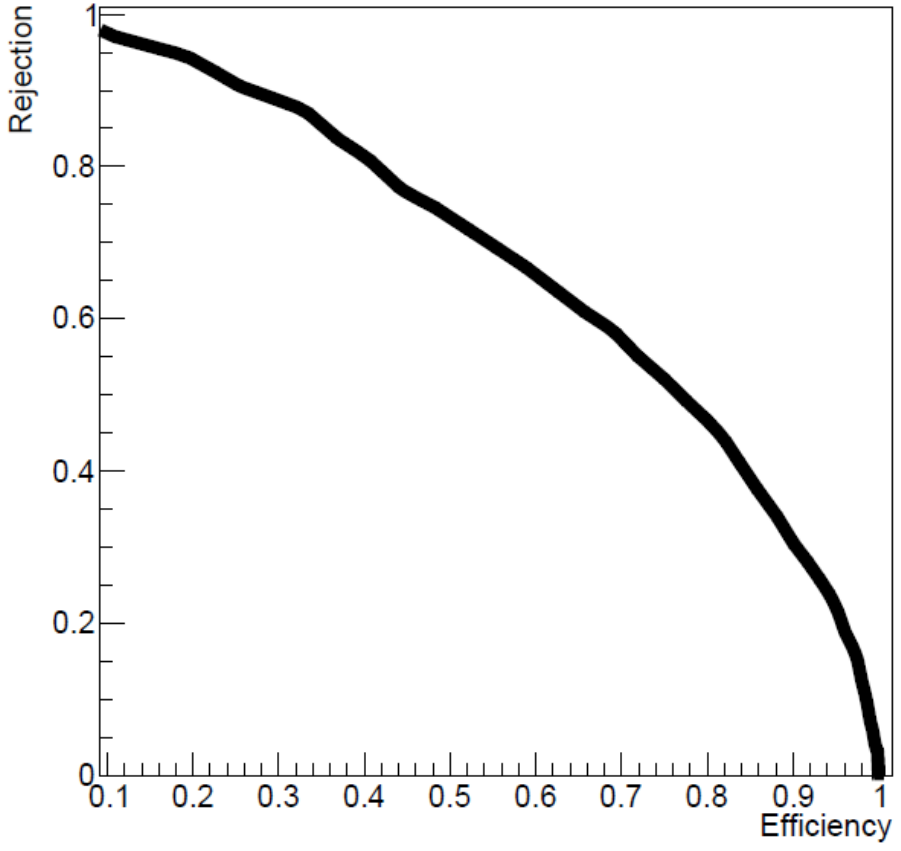

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Ensemble learning combines the results of multiple learning algorithms in order to produce better predicative power than either algorithm on its own

Our method:

Using the MC to train BDTs (via TMVA) and output the results (the training sample) as a variable

"Bagging":

Each model is trained over the same MC set. Samples are chosen for testing and training at random.

BDT and ANN outputs are converted to variables and used as the sole variables over the course of a third training of the ANN

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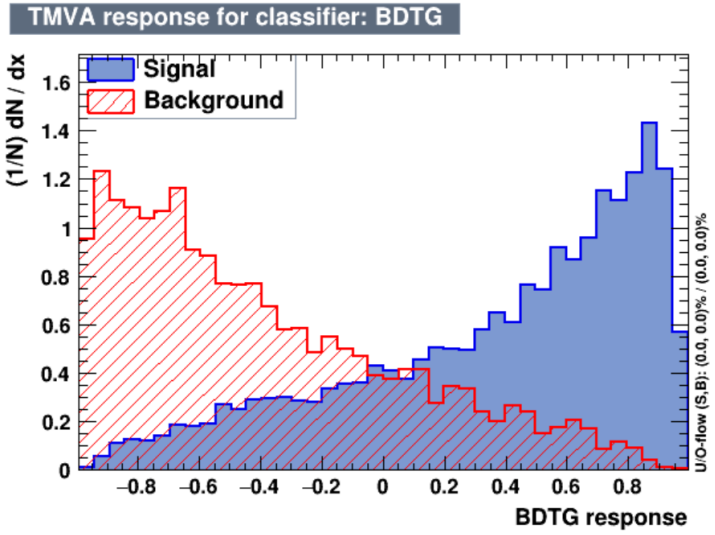
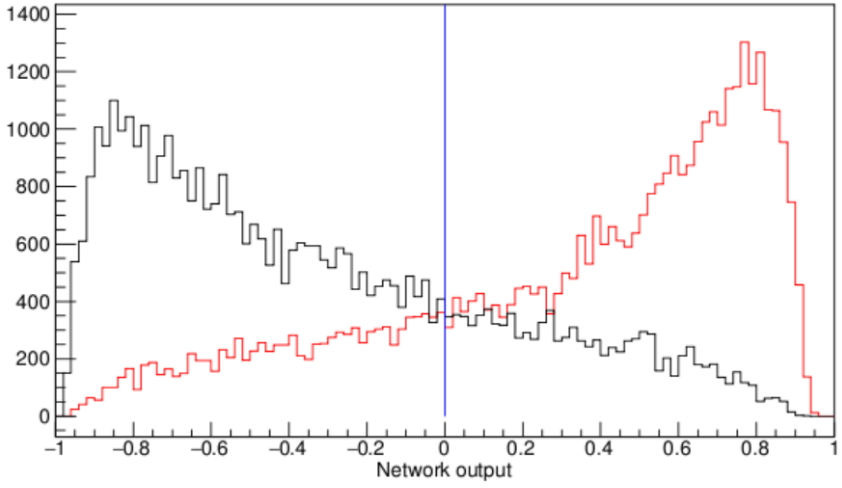
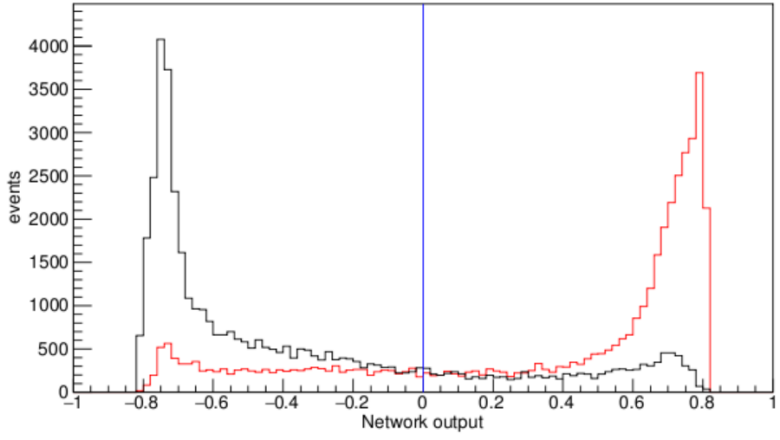
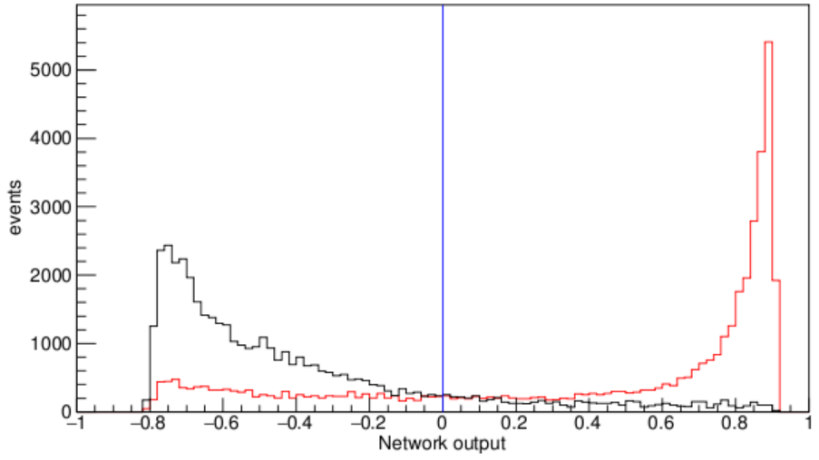
Direct Comparison- Separation achieved by each method









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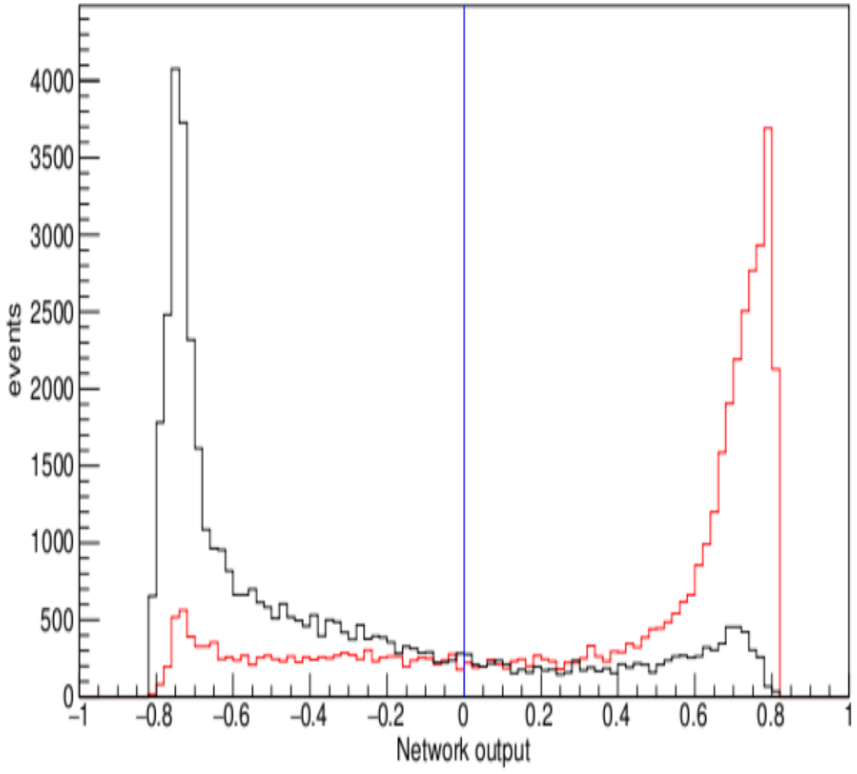

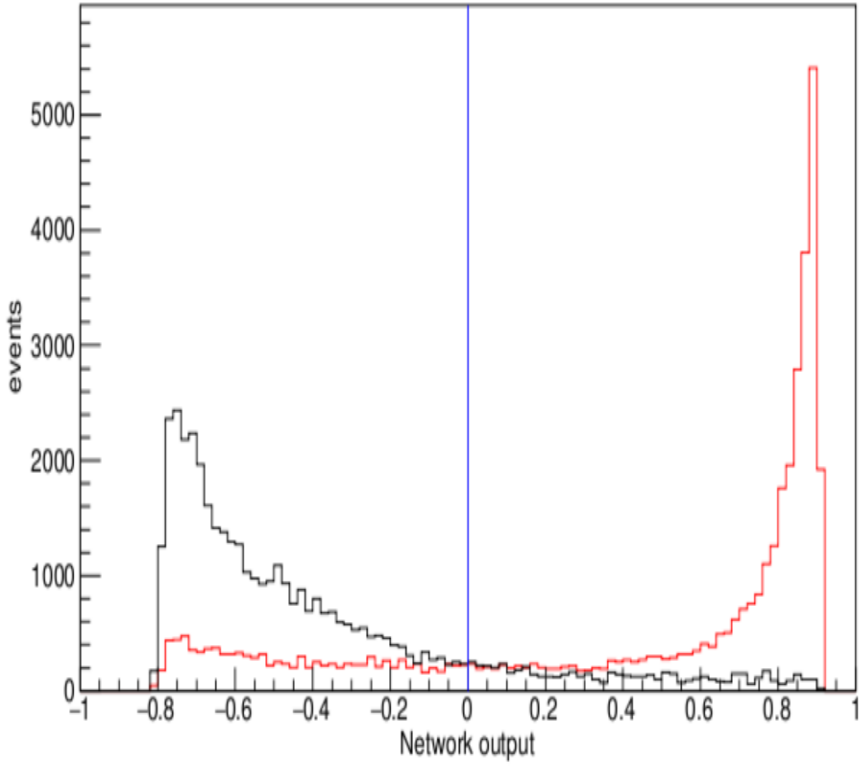

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While this project is moving forward without ensemble techniques, verification could lead to use in future work

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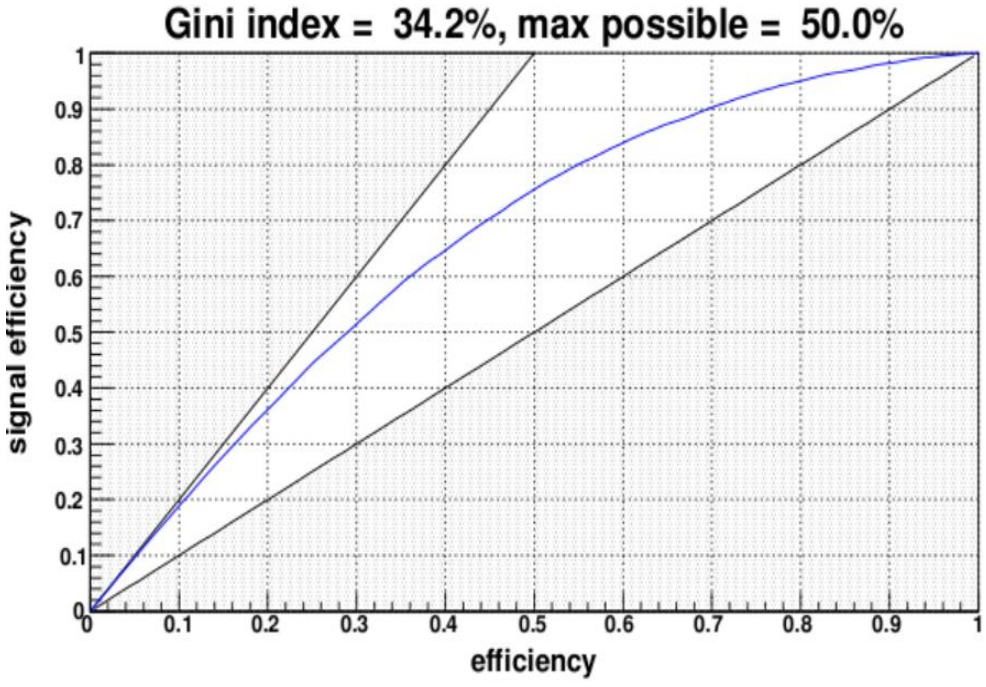
- More verification of usefulness is needed before real application



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