Spin Correlation in Top Quark Pair Decay: An Approach with Machine Learning for Super Symmetric Exploration

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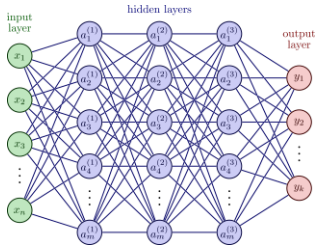
Abstract

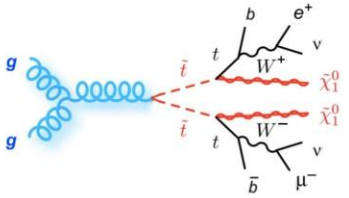
- The search for evidence supporting the Supersymmetric model by leveraging data obtained from FastSim (Delphes) as a projection study for the HL-LHC upgrade
- Focusing on the spin correlation observables of top quark pair decay, we utilized histograms to identify patterns and deviations within the data
- Utilized machine learning techniques using PyTorch to enhance ability to identify patterns and draw conclusions regarding the potential presence of the SUSY model

Neural Network Process

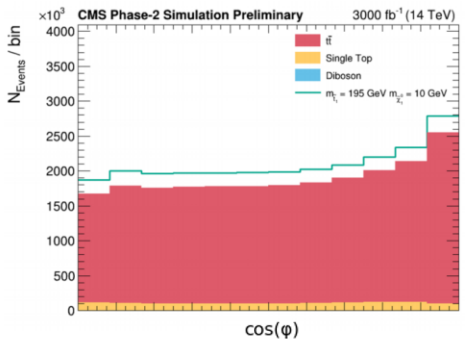
- Separate SM and SUSY data to form our "answer sheet"
- Combine data to put into our NN
- Split the combined set into training and testing sets
- The NN is given the input (pt, in this case) and returns a binary value for SM or SUSY
- Training is done in rounds, called epochs
- After training, measure the accuracy of our model with testing

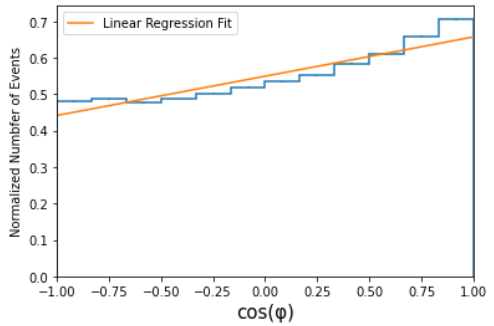


Overview of Neural Networks



Feynman Diagrams of Top Quark Decay Processes in the SUSY model





The CMS group produced the left graph for their research on this subject. Our version is on the right.

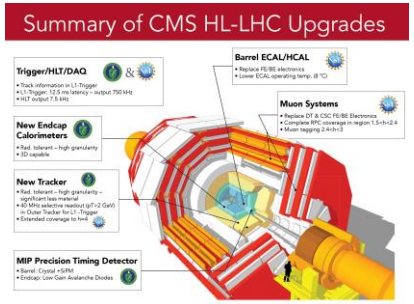
Spin Correlation

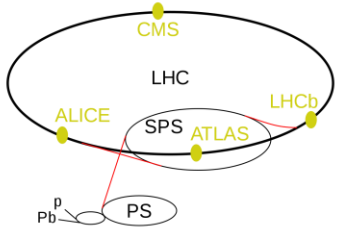
- Use the slope of the LR line (orange) to find D in the lower equation (right)
- Alternatively, use the values of the bins from the plot in the upper equation (right)
- D is called a "Spin Correlation Observable"
- Helpful in understanding the production and decay of Top Quarks

$$A_{\cos\varphi}^{\text{lab}} = \frac{N(\cos\varphi_{\text{lab}} > 0) - N(\cos\varphi_{\text{lab}} < 0)}{N(\cos\varphi_{\text{lab}} > 0) + N(\cos\varphi_{\text{lab}} < 0)},$$

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\varphi} = \frac{1}{2}(1 - D\cos\varphi)$$

Spin Correlation Coefficient Equations





Large Hadron Collider Diagram

Analysis

- Utilizing Standard Model data as a reference background enables the identification and analysis of potential signatures indicative of Supersymmetry phenomena
- While the Standard Model serves as the current cornerstone of particle physics, Supersymmetry introduces an additional layer of theoretical complexity, offering promising avenues to address unresolved questions in the field.
- Efforts to validate or challenge the existence of Supersymmetry involve categorizing particle collision data into discrete bins, with analysis of decay patterns specific to each collision event
- Additionally, this research delves into the use machine learning techniques to refine and expand upon Supersymmetry theories

Conclusion

- Using data from both Supersymmetry (SUSY) and the Standard Model (SM), the spin correlation coefficient D is extracted from the slope of the lepton momentum plotted against cos(φ), providing valuable insights for analytical investigations
- Through machine learning techniques, we developed efficient methods for identifying trigger points in particle collision data to understand the resulting particles from these collisions

Future Work

- Expand our NN model to include Multi-Dimensional Analysis
- Accurately identify decay collisions with the Large Hadron Collider's High Luminosity (LHC-HL) upgrades
- Test and refine the neural network's performance with various particle collision events

Reference

The CMS Collaboration. "Projection of the Top Quark Spin Correlation Measurement ..." CERN, CERN, 28 June 2022, cds.cern.ch/record/2813262/files/FTR-18-034-pas.pdf.