Bs > τ+ τ- with the FCC-ee experiment at 91GeV

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Monte Carlo Samples for Bs > τ+ τ-

Oficial samples from winter 2023 campaign

Signal samples, 10M events

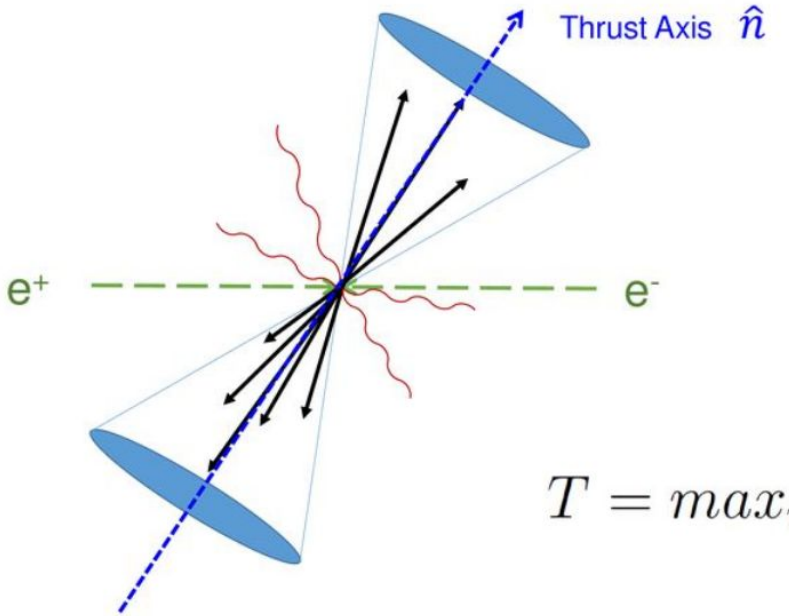
- Z > bb~, Bs > τ+ τ-, τ > 3π + ν (Exclusive)
- Z > bb, Bs > τ+ τ-, τ > others

Background samples, 500M events each

- Z > bb~ inclusive
- Z > cc~ inclusive
- Z > ss~ inclusive (No high impact)
- Z > ud~ inclusive (No high impact)

Thrust Axis definition

- Process: Z > bb~, Bs > τ+ τ-, τ > 3π + ν
- The thrust axis is define as the unitary vector n, that maximize the Thrust

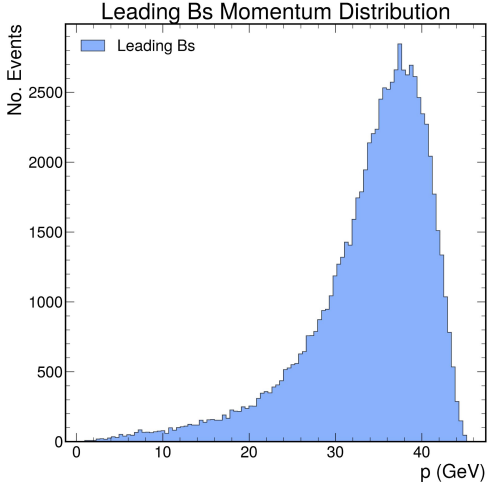


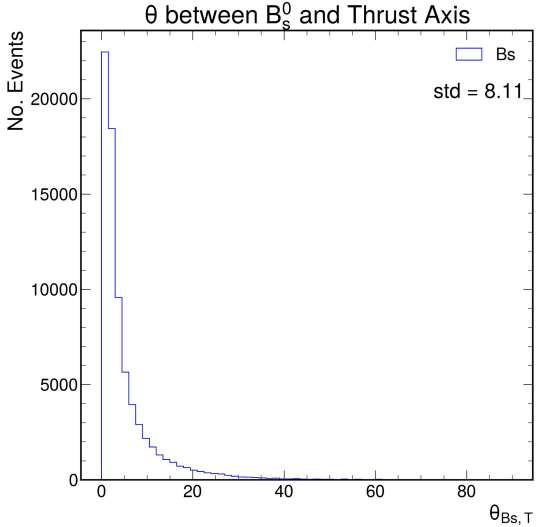
$$T = max_{\hat{n}} \frac{\sum_i |\hat{p}_i . \hat{n}|}{\sum_i |\hat{p}_i|}$$

Bs > τ+ τ- kinematics

Some distributions of the Bs > **ττ**.

- Energy and momentum distributions for Bs
- **Ideal case:** For perfect reconstruction, the Bs should be collinear with the thrust axis.

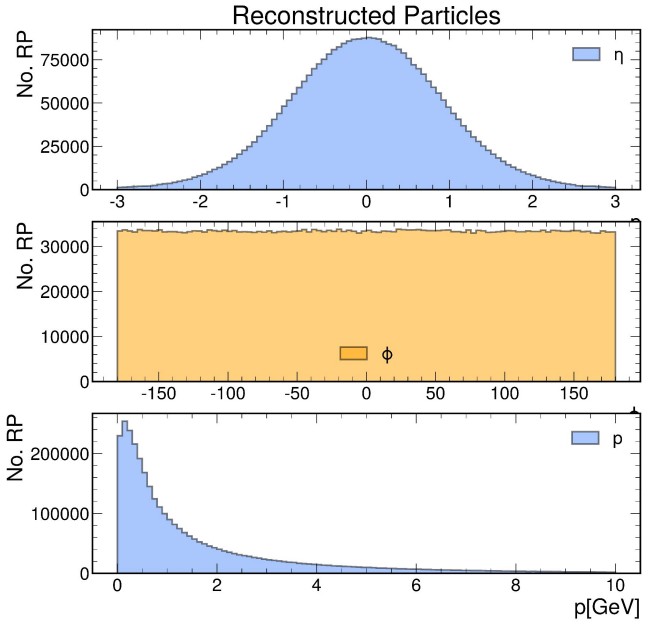


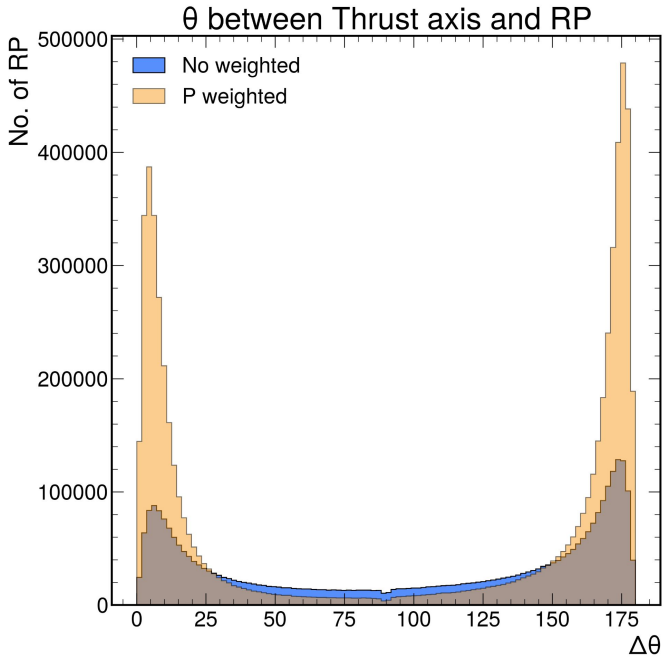


Reconstruction studies

Kinematics of reconstructed particles (RP)

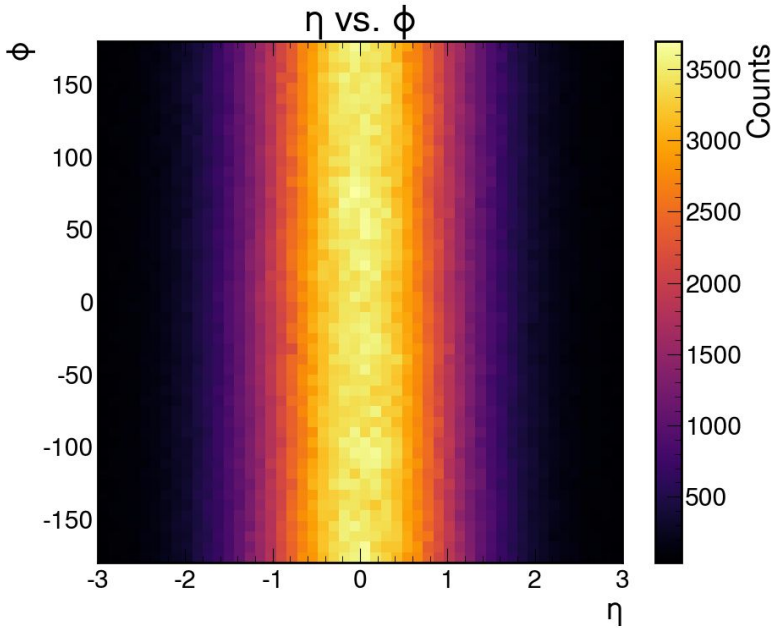
- RP are cluster mostly around the Thrust axis as expected

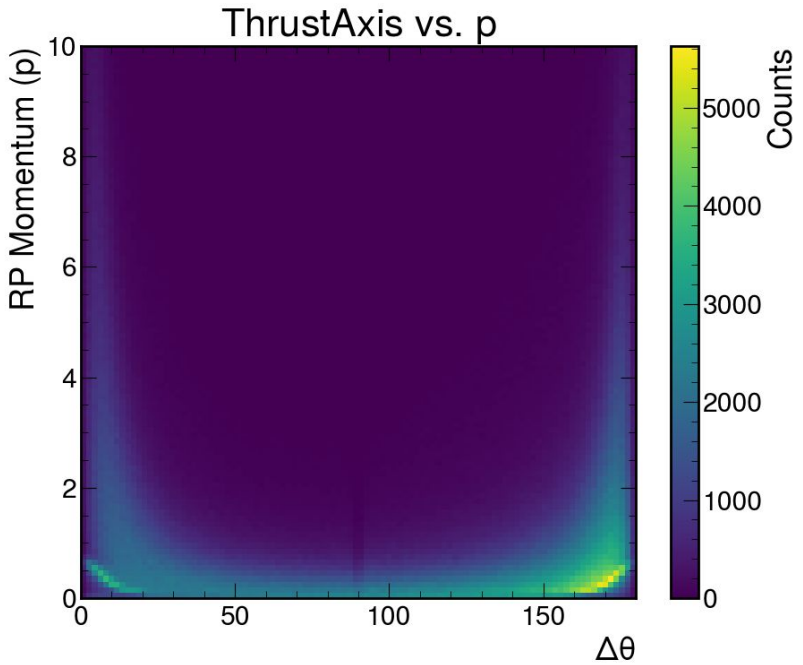




Reconstruction studies

2D Histograms for Reconstructed particles

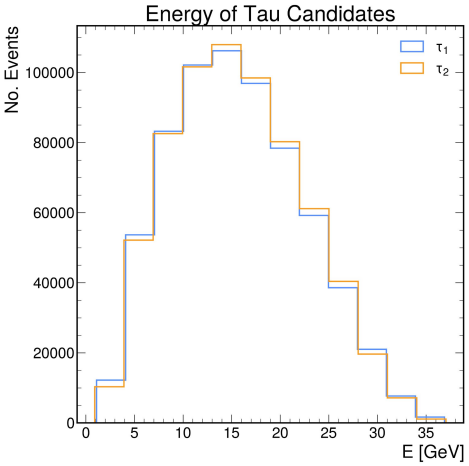


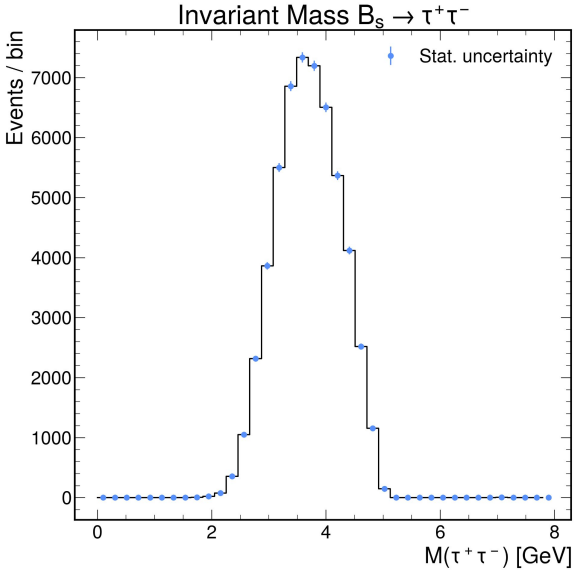


τ+ τ- system kinematics

Identify the two tau candidates in the signal hemisphere.

- Extract features for each tau candidate (px,py,pz,p,E)
- Calculate the visible mass of the **ττ** system
- Current invariant mass resolution can be improved





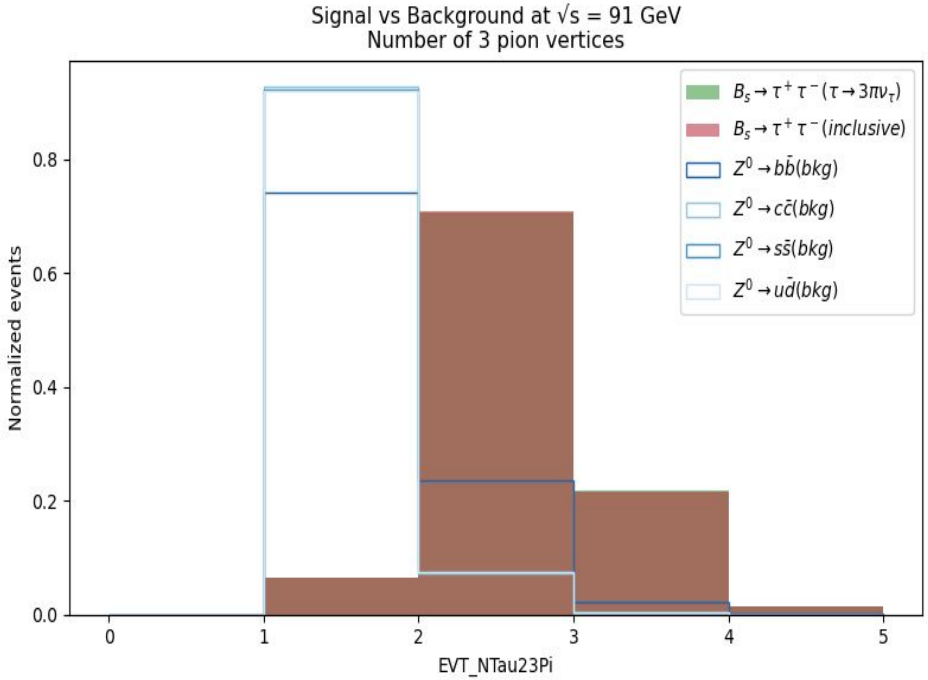
Bs > τ+τ-

High-Level Variable Distributions

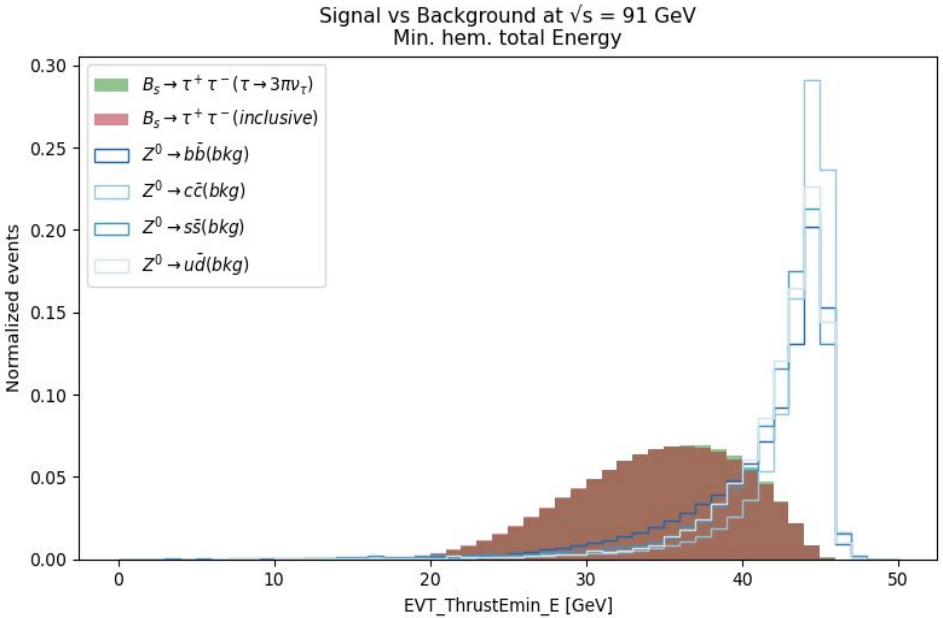
Number of 3 pion vertices

Signal: For the decay $B_s \rightarrow \tau^+\tau^-$, with $\tau \rightarrow 3\pi\ \nu_\tau$, we naturally expect 3 pions to be detected. Even for the inclusive sample we expect a higher number of pions, because of the tau decay channels

Background: It does not reproduce the 3-pion final state. Important background here comes from D mesons, because it decays also into 3 pions



Min. Hemisphere total Energy



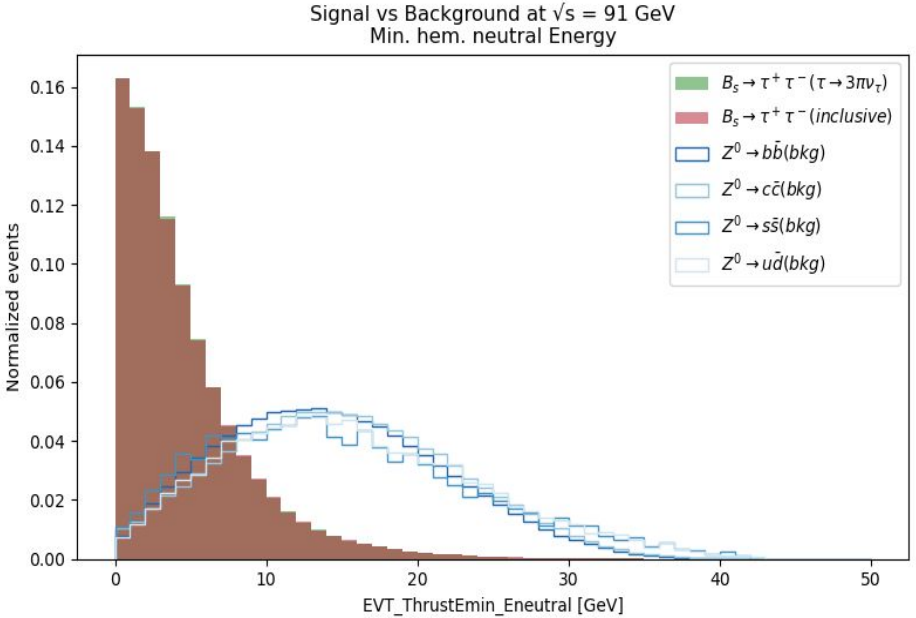
Signal: The signal lose significant energy because of the neutrinos, which always escape detection.

Background: Each hemisphere have ~45.5 GeV. Bkg events tend to produce more balanced energy distributions (jets)

Min. Hemisphere neutral Energy

Signal: Peak at 0 GeV. This is expected because the neutrinos are never detected.

Background: Jets produce a wide range of particles with different energies, that's why here the peak is also broader



Machine Learning Performance Comparison

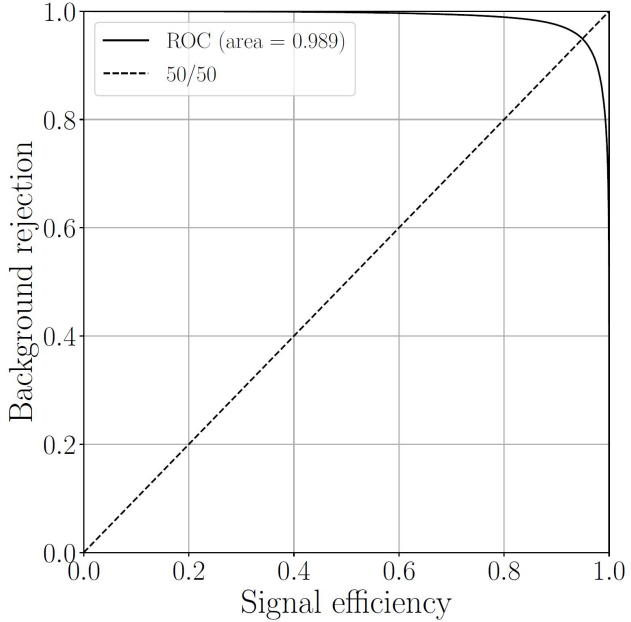
Overview

- Stage 1 analysis using event Level variables e.g. number of 3 Pion vertices
- Aim: Binary classifier distinguishing $B_S \rightarrow \tau\tau \rightarrow$ 6 π from qq background
- Later: Classification of more decay channels

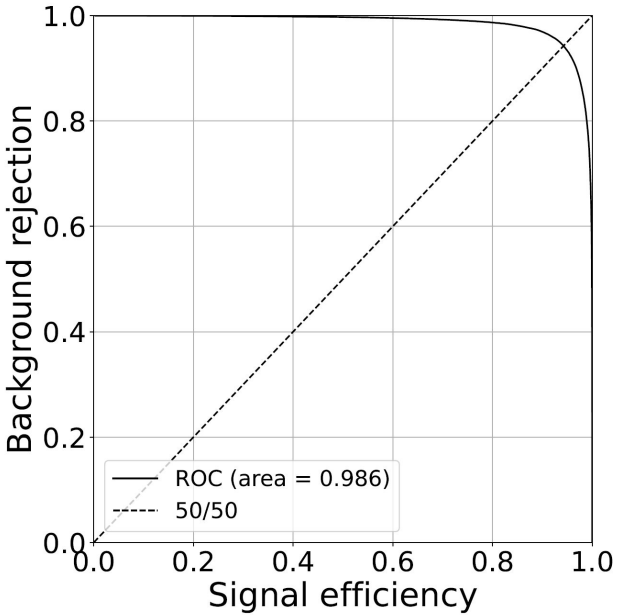
  →Use a gradient boosted tree and a Multi Layer Perceptron and compare performance

  →Extract feature importance

ROC comparison

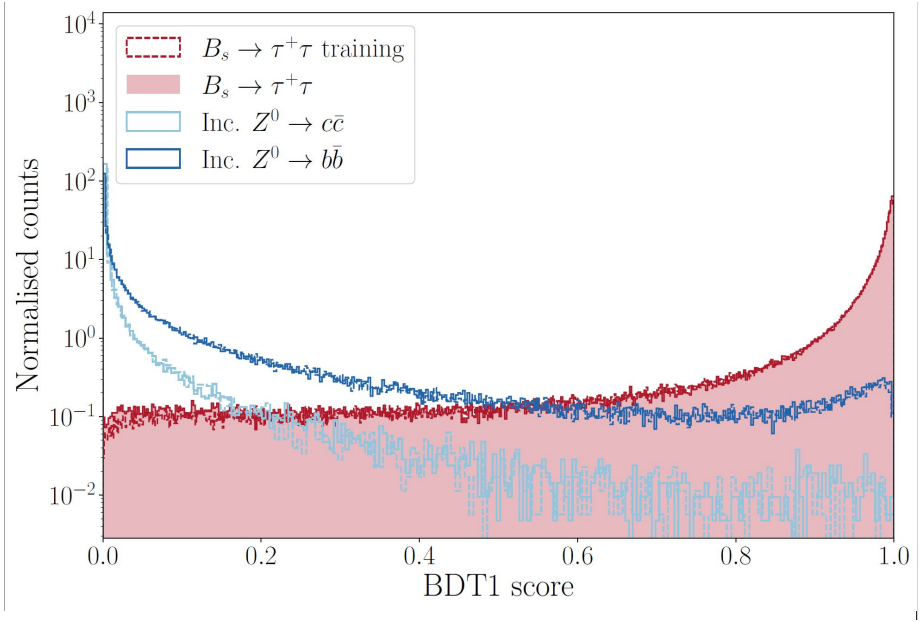


Gradient boosted tree

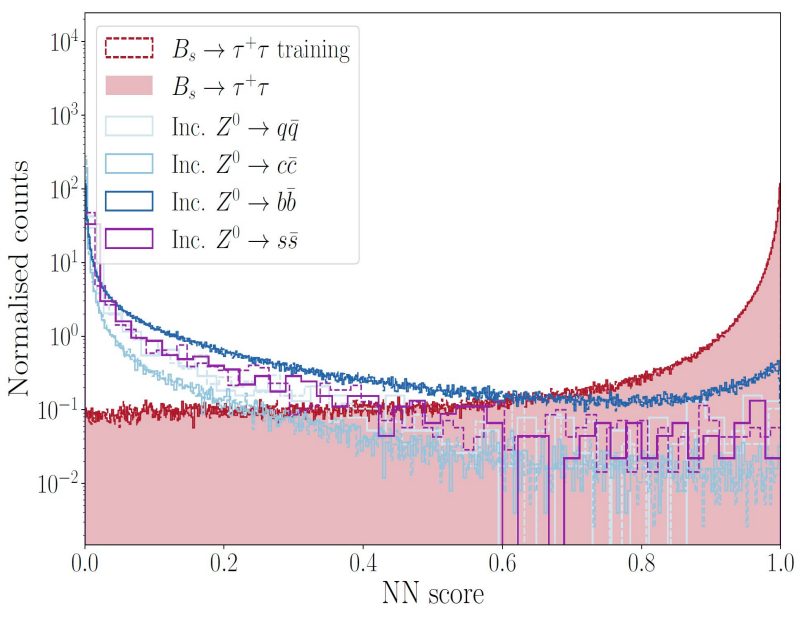


Multi Layer Perceptron

Signal vs. Background scores

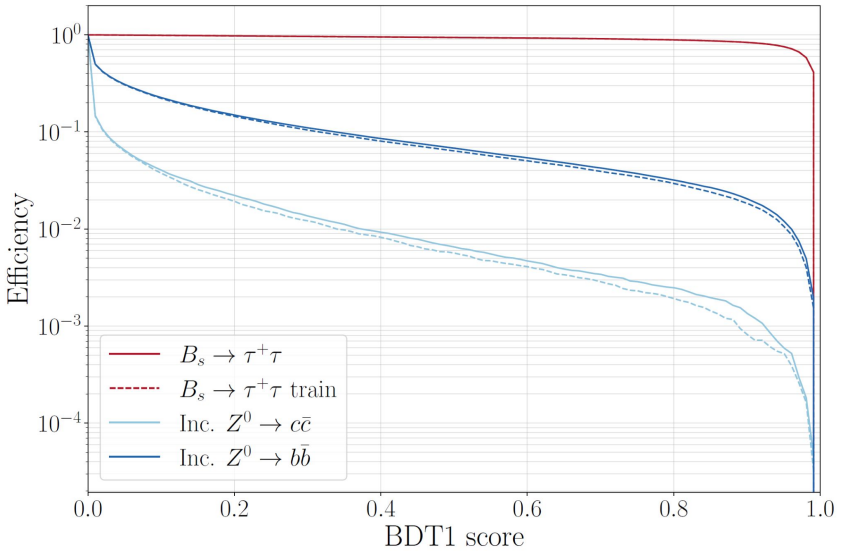


Gradient Boosted Tree

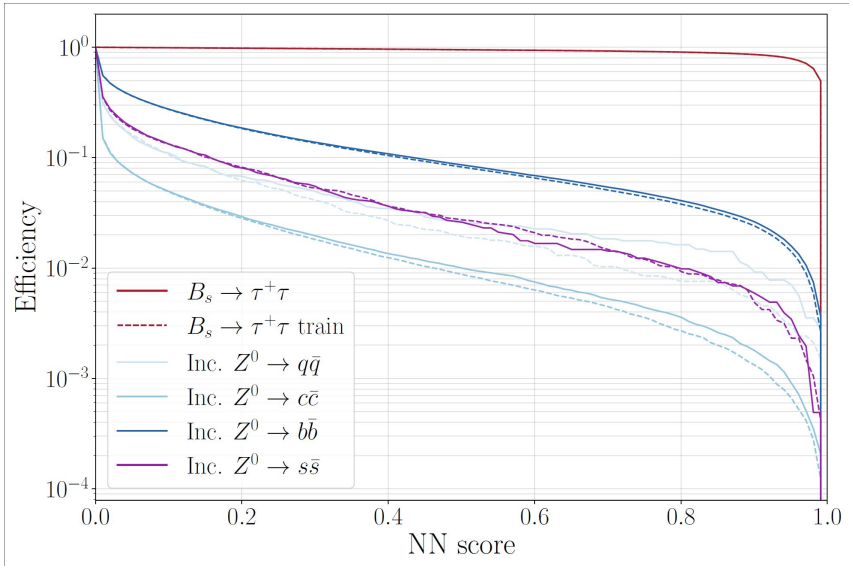


Multi Layer Perceptron

Signal vs. Background Efficiency



Gradient Boosted Tree



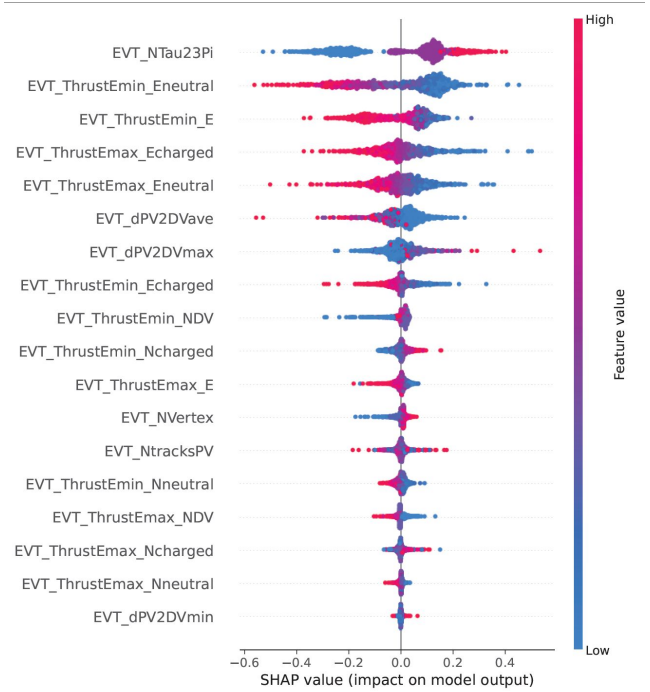
Multi Layer Perceptron

Feature importances

Gradient Boosted Tree:

Variable	Importance
Number of 3π candidates	0.71
Minimum hemisphere total energy	0.1
Minimum hemisphere neutral energy	0.08
Number of secondary vertices in the minimum hemisphere	0.036

Multi Layer Perceptron:



Thank you

Backup

All Input variables for the BDT1

Event - level variables

Variable name	Description
EVT_ThrustEmin_E	Minimum hemisphere total energy
EVT_ThrustEmax_E	Maximum hemisphere total energy
EVT_ThrustEmin_Echarged	Minimum hemisphere charged energy
EVT_ThrustEmax_Echarged	Maximum hemisphere charged energy
EVT_ThrustEmin_Eneutral	Minimum hemisphere neutral energy
EVT_ThrustEmax_Eneutral	Maximum hemisphere neutral energy
EVT_ThrustEmin_Ncharged	Charged multiplicity in minimum hemisphere
EVT_ThrustEmax_Ncharged	Charged multiplicity in minimum hemisphere
EVT_ThrustEmin_Nneutral	Neutral multiplicity in minimum hemisphere
EVT_ThrustEmax_Nneutral	Neutral multiplicity in maximum hemisphere

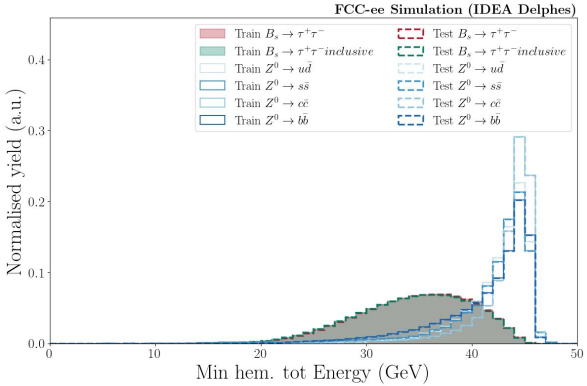
Input variables for the BDT1

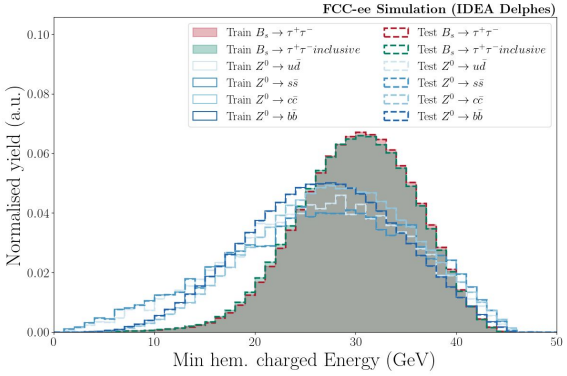
Vertex - level variables

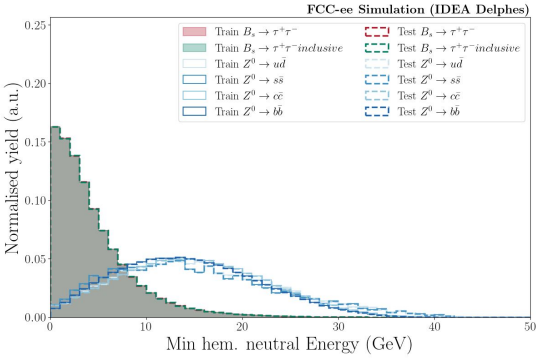
Variable name	Description
EVT_NtracksPV	Number of tracks from PV
EVT_NVertex	Number of reco vertices
EVT_NTau23Pi	Number of 3pions vertices
EVT_ThrustEmin_NDV	Number of secondary vertices in min hemisphere
EVT_ThrustEmax_NDV	Number of secondary vertices in max hemisphere
EVT_dPV2DVmin	Min distance between SVs to PV (mm)
EVT_dPV2DVmax	Max distance between SVs to PV (mm)
EVT_dPV2DVave	Mean distance between SVs to PV (mm)

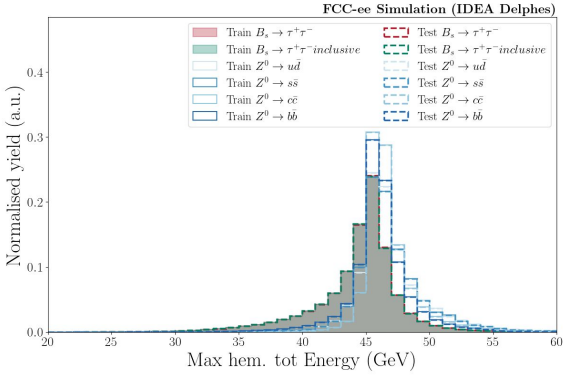
Backup

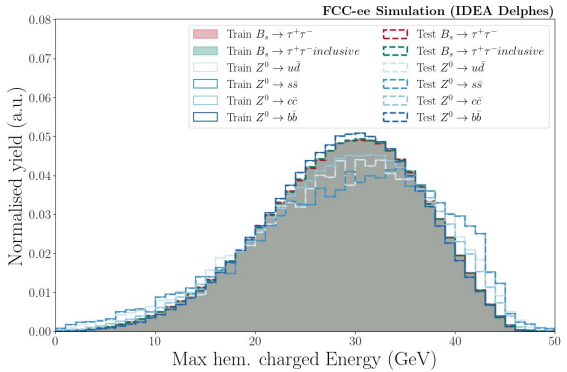
BDT input variables event- level

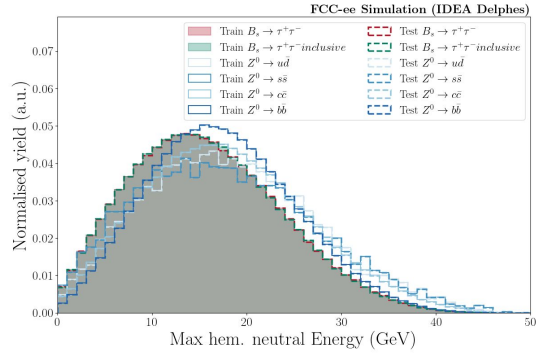






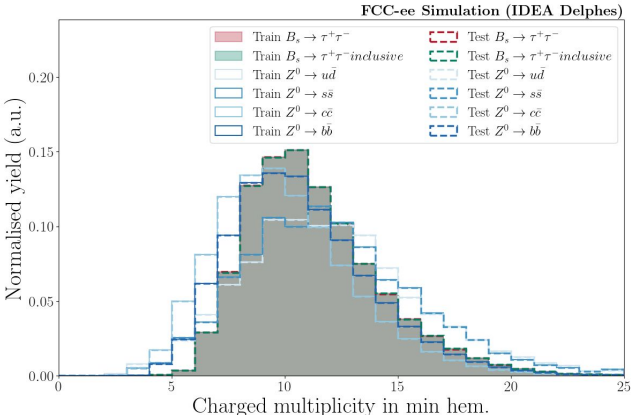


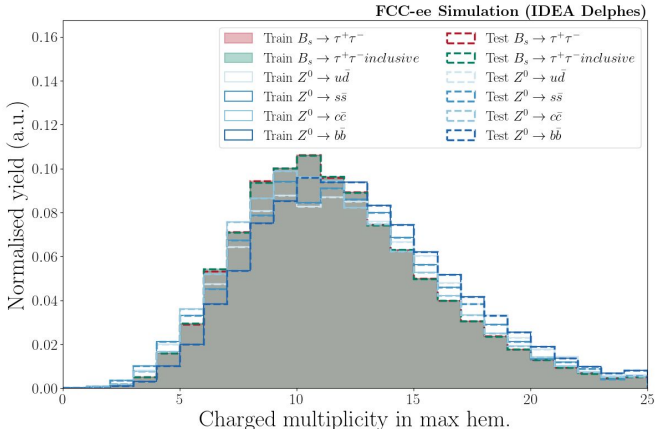


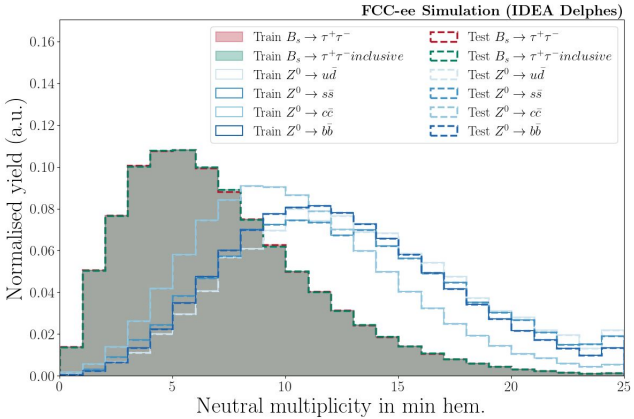


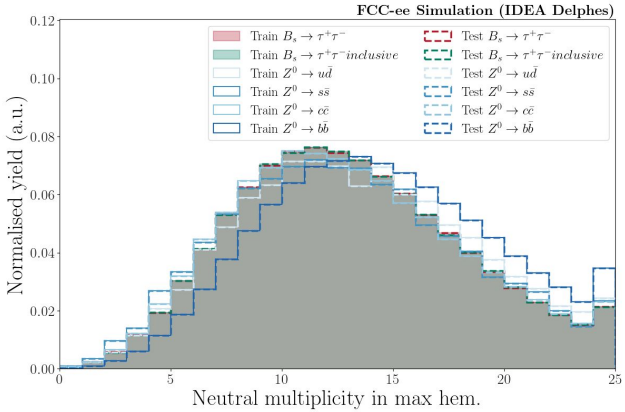
Backup

BDT input variables event - level



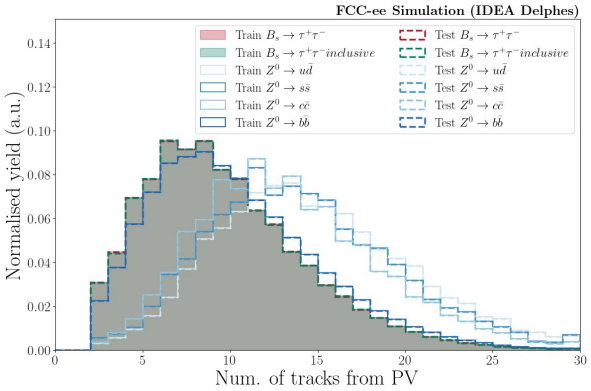


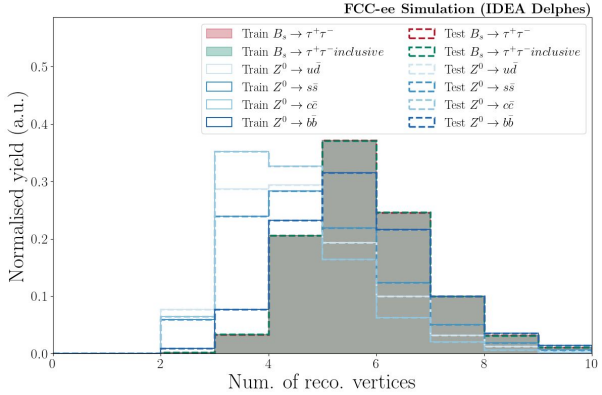


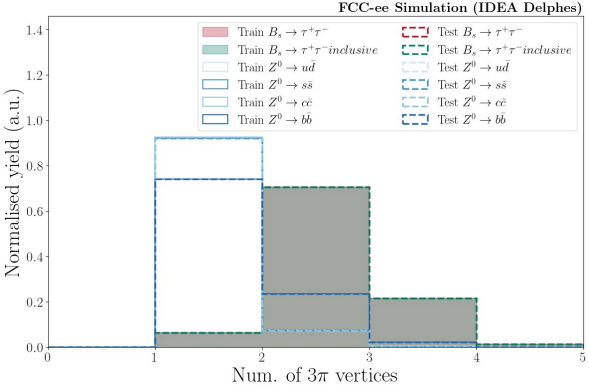


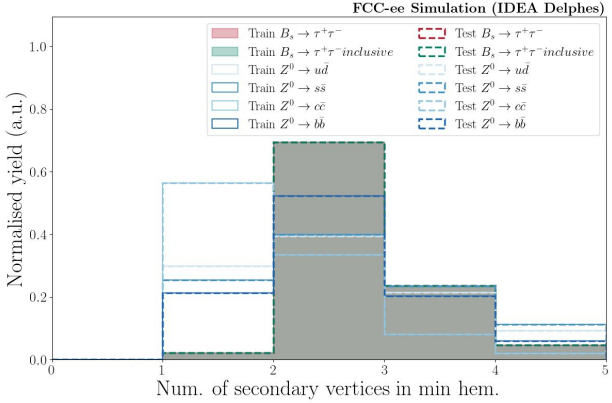
Backup

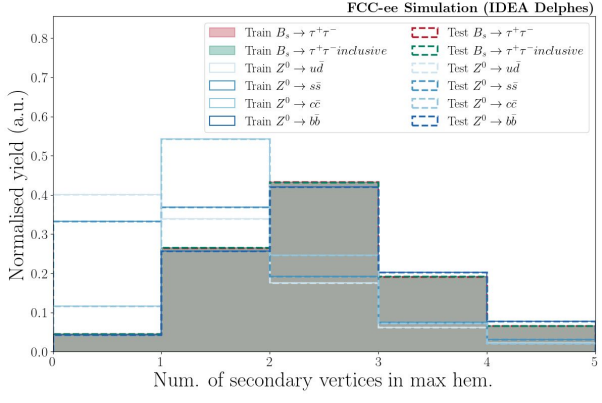
BDT input variables vertex - level

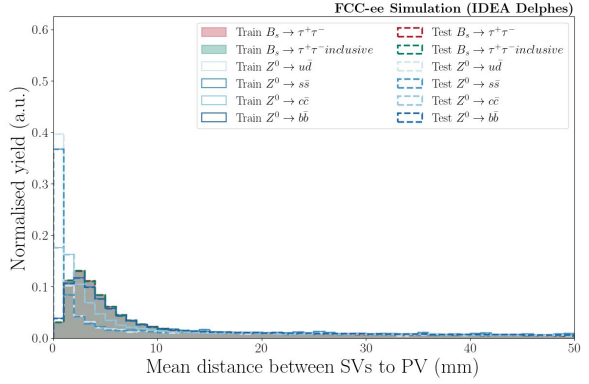






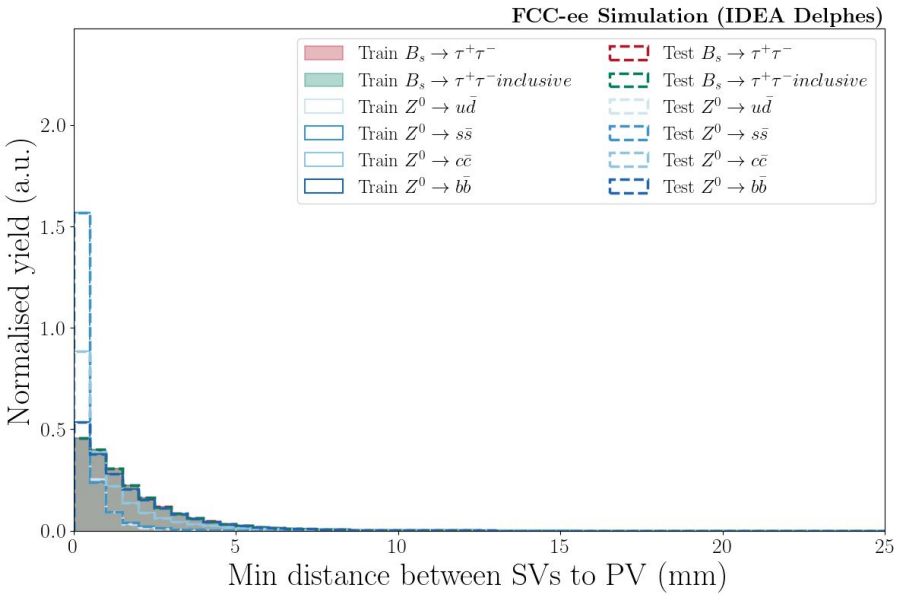


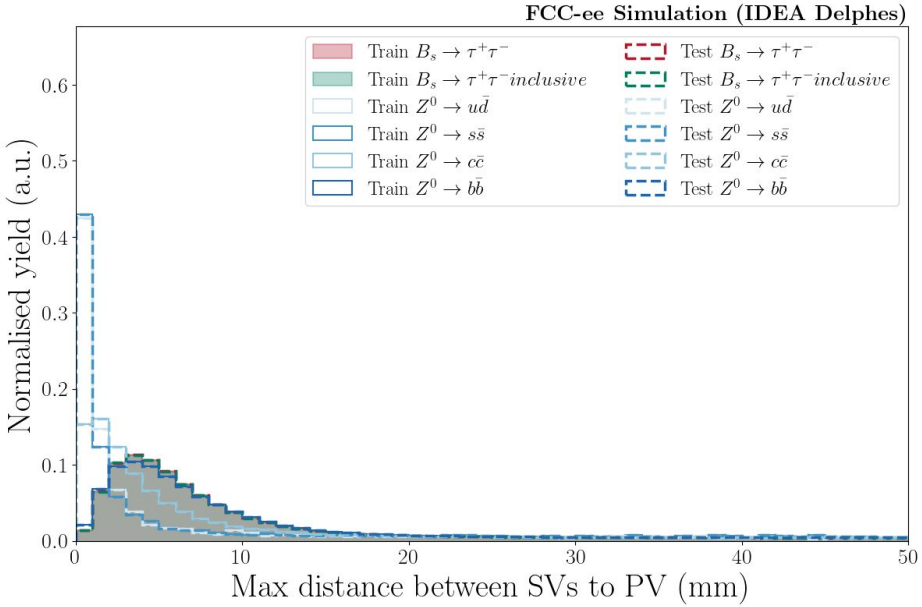




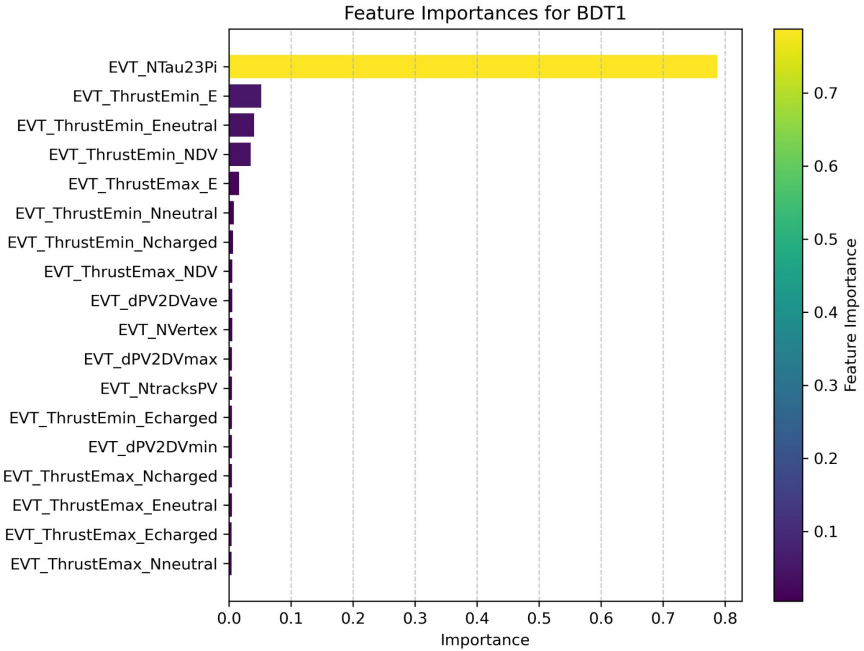
Backup

BDT input variables vertex - level

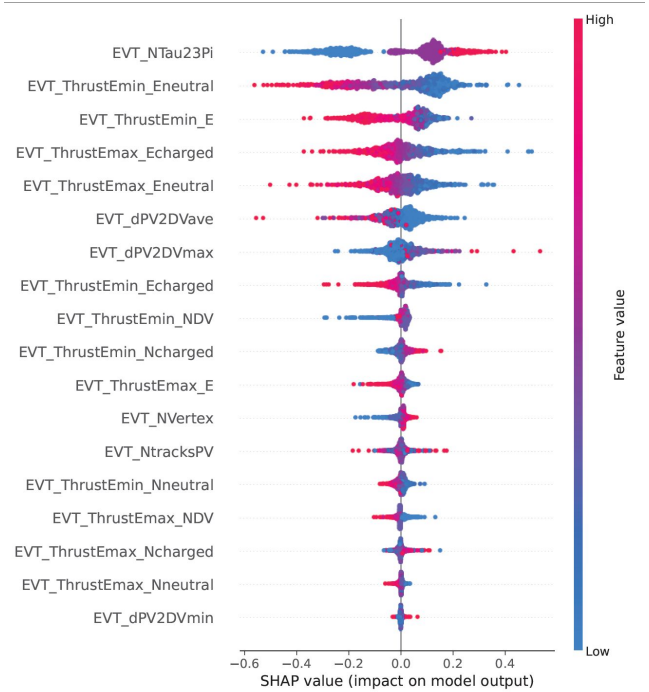




Feature importance BDT1 vs NN



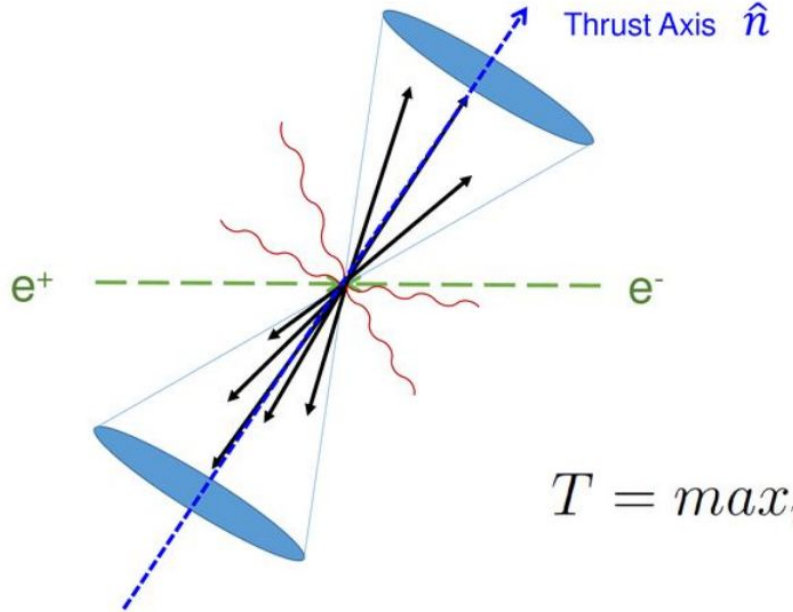
BDT



NN

Thrust Axis definition

The thrust axis is define as the unitary vector n, that maximize the Thrust



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