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Search for $D^0 \rightarrow$ invisible final states in Belle II experiment

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Abstract

We measured the branching fraction of $D^0 \rightarrow K^-\pi^+$ control mode decay and the upper limit of Branching fraction of D^0 to invisible final states signal mode on 1 ab^{-1} generic MC which contains mixed, charged, $q\bar{q}(q = u, d, s, c)$ events. the measurement of absolute branching fraction of the signal and control mode is performed with charm tagging method. the results are shown in the below.

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6 1 Motivation

7 In standard model, the decay D^0 to the invisible final states correspond to the $D^0 \rightarrow \nu\bar{\nu}$
 8 decay and its Feynmann diagrams are shown in Figure 1. however as shown in the figure
 9 2, the $D^0 \rightarrow \nu\bar{\nu}$ is helicity suppressed with expected branching fraction of 10^{-30} order,
 10 which is beyond current collider experiment. but the $\text{Br}(D^0 \rightarrow \text{invisible})$ can be enhanced
 11 in some of dark matter model. if signal is observed, then it would be a sign of new physics.
 12 in other words, the search for D^0 to the invisible final states is very sensitive to new physics.

13

14 The previous research in Belle expeirment had result of upper limit estimation of
 15 Branching fraction. its value is 9.4×10^{-5} at 90% conference level on 924fb^{-1} data
 16 samples.

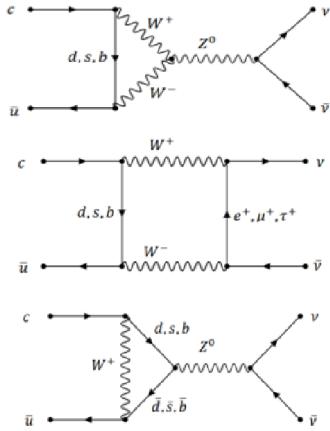


Figure 1: Feynman diagram of signal MC

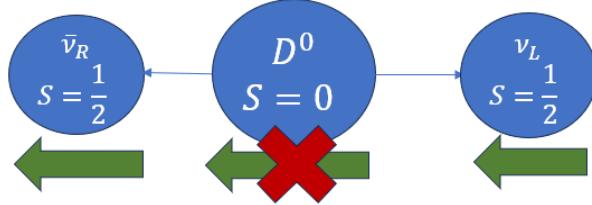


Figure 2: Scheme of helicity supressing

17 2 Data Sample

18 The analysis is based on the 1ab^{-1} MC15 run independent samples that contains
 19 mixed, charged and $q\bar{q}$ ($q = u, d, s, c$) events and the signal MC which have 20M $e^+e^- \rightarrow$
 20 $c\bar{c} \rightarrow D_{tag}X_{frag}D_{sig}^{*+}$ and $D_{sig}^{*+} \rightarrow D_{sig}^0\pi^\pm$ and $D_{sig}^0 \rightarrow \nu\bar{\nu}$ event and 20M $D^0 \rightarrow K^-\pi^+$
 21 events as control sample.

22 3 Charm tagger : Inclusive D^0 reconstruction

23 3.1 Overview

24 Since the signal D^0 is invisible, so direct reconstruction of signal D^0 is not possible.
 25 so, we need to reconstruct the signal D^0 indirectly. To obtain the inclusive D^0 sample,
 26 the process followed by $e^+e^- \rightarrow c\bar{c}$ which we are going to reconstruct is

$$27 \quad e^+e^- \rightarrow c\bar{c} \rightarrow D_{tag}^{(*)}X_{frag}D^{*+}, D^{*+} \rightarrow D^0\pi^+$$

28 Through this process, one of the c quark hadronizes into $D_{tag}^{(*)}$, which is going to be
 29 reconstructed as tag side. $D_{tag}^{(*)}$ includes ground state $D_{tag}(D^0, D^+, D_s^+ \text{ and } \Lambda_c^+)$ and ex-
 30 cited state $D_{tag}^*(D^{*0}, D^{*+} \text{ and } D_s^{*+})$. Since the CM energy of KEKB is above the $c\bar{c}$ mass
 31 threshold, for the $e^+e^- \rightarrow c\bar{c}$ production, besides two hadrons with c flavor would be
 32 generated from the 2 c jets, other unflavored mesons would also be generated from frag-
 33 mentation, which is denoted as X_{frag} . X_{frag} consists of any number of pions or γ , and
 34 even number of Kaons. The information of recoil D^* is the missing momentum against
 35 the reconstructed $D_{tag}^{(*)}$ and X_{frag} . We use the inverse mass constrained fit to improve the
 36 resolution of recoil D^* momentum and to suppress background from many fragmenation
 37 particle combinations. With tagging on a extra slow π^+ from recoil D^{*+} , we can finally
 38 reconstruct the inclusive D^0 . The yield of inclusive D^0 is obtained by the fit on missing
 39 mass distribution recoiling against $D_{tag}^{(*)}$, X_{frag} and π_s^+ .

40
 41 One example of the signal events that consist of $D_{tag}^* = D^{*+}(\rightarrow D^+(\rightarrow K^-\pi^+\pi^+)\pi^0)$
 42 and $X_{frag} = K^+K^-$ is the below figure. In this example, I reconstructed $D^{*+} \rightarrow D^+(\rightarrow$
 43 $K^-\pi^+\pi^+)\pi^0$ and K^+K^- directly and then reconstruct signal side D^{*-} by calculating
 44 missing momentum against of this D_{tag}^* and X_{frag} .

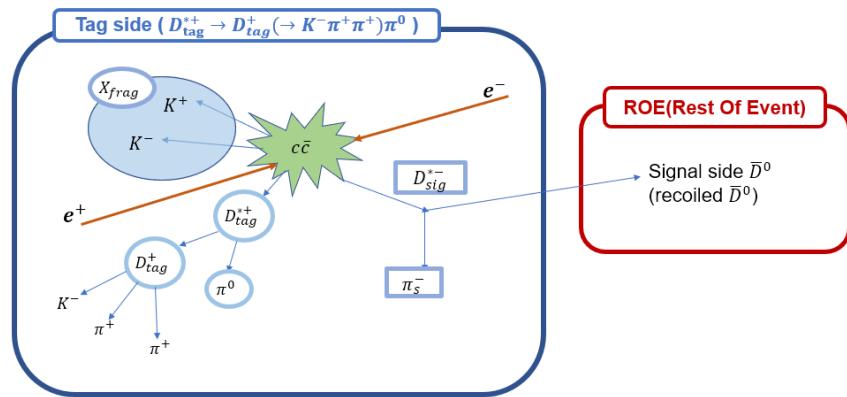


Figure 3: one example of signal events

45 Measurement of absolute branching fraction of D^0 to an exclusive final state f is
 46 determined by this formula:

$$47 \quad \text{Br}(D^0 \rightarrow f) = \frac{N_{excl}(D^0 \rightarrow f)}{N_{incl}^{D^0} \cdot \epsilon(D^0 \rightarrow f | incl.D^0)}$$

48 where $N_{incl}^{D^0}$ represents the total number of inclusive D^0 reconstructed by the charm tagger,
 49 $N_{excl}(D^0 \rightarrow f)$ is signal yield of exclusive $D^0 \rightarrow f$ decay, and the $\epsilon(D^0 \rightarrow f | incl.D^0)$
 50 is the signal side selection efficiency of $D^0 \rightarrow f$ decay with a given inclusive D^0 sample.
 51 Basically, the signal side selection is usually constraints on the remaining detector
 52 information for specific D^0 . For instance, we will require there is no remaining detector
 53 information at signal side for $D^0 \rightarrow \nu\bar{\nu}$ study.

54 In order to get better statistics, we reconstruct as many tag side decay channels as possible.
 55 for this reason, one of the main background source is from mis-reconstruction of tag
 56 side. So, the BDT is also being used for suppressing background from mis-reconstructed
 57 tag side.

58 This signal event reconstruction procedure is called as Charm Tagger and basf2 release-
 59 06 is used for MC production and basf2 [light-2405-quaxo](#) version is used for reconstruction.

60 3.2 D_{tag} reconstruction

61 The first step is to reconstruct the ground state charm hadron D_{tag} . I used 4 types of
 62 D_{tag} and totally 51 decay channels are reconstructed and all these channels are listed in
 63 Table 1. All reconstructions except for $D^0 \rightarrow K_S^0\pi^0$, $D^+ \rightarrow \pi^+\pi^0$ and $\Lambda_c^+ \rightarrow \Sigma^+\pi^0$ were
 64 done with vertex fit. applying vertex fit on these 3 channels is not possible due to degree
 65 of freedom issue for vertex fit.

D^0 decay	$Br(\%)$	D^+ decay	$Br(\%)$	Λ_c^+ decay	$Br(\%)$	D_s^+ decay	$Br(\%)$
$K^-\pi^+$	3.9	$K^-\pi^+\pi^+$	9.4	$pK^-\pi^+$	5.0	$K^+K^-\pi^+$	5.5
$K^-\pi^+\pi^0$	13.9	$K^-\pi^+\pi^+\pi^0$	6.1	$pK^-\pi^+\pi^0$	3.4	$K_S^0K^+$	1.5
$K^-\pi^+\pi^+\pi^-$	8.1	$K_S^0\pi^+$	1.5	pK_s^0	1.1	$K_S^0K_S^0\pi^+$	5.4
$K^-\pi^+\pi^+\pi^-\pi^0$	4.2	$K_S^0\pi^+\pi^0$	6.9	$\Lambda^0\pi^+$	1.1	$K^+K^-\pi^+\pi^0$	5.6
$K_S^0\pi^+\pi^-$	2.9	$K_S^0\pi^+\pi^+\pi^-$	3.1	$\Lambda^0\pi^+\pi^0$	3.6	$K_S^0K^-\pi^+\pi^+$	1.5
$K_S^0\pi^+\pi^-\pi^0$	5.4	$K^+K^-\pi^+$	1.0	$\Lambda^0\pi^+\pi^+\pi^-$	2.6	$K^+\pi^-\pi^+K_S^0$	1.0
$K^-\pi^+\pi^0\pi^0$	8.9	$K^-K^+\pi^+\pi^0$	0.7	$p^+\pi^-\pi^+$	0.5	$\pi^+\pi^-\pi^+$	1.0
$\pi^-\pi^+$	0.1	$\pi^-\pi^+\pi^+$	0.3	$p^+K^-K^+$	0.1	$\pi^+K_S^0$	0.1
$\pi^-\pi^+\pi^-\pi^+$	0.8	$\pi^-\pi^+\pi^+\pi^0$	1.2	$p^+K^-\pi^+\pi^0\pi^0$	0.1	$\pi^+\pi^0K_S^0$	0.5
$\pi^-\pi^+\pi^0$	1.5	$K^+K_S^0K_S^0$	0.3	$p^+\pi^-\pi^+\pi^-\pi^+$	0.2	$K^-K^+\pi^+\pi^-\pi^+$	0.7
$\pi^-\pi^+\pi^0\pi^0$	1.0	$\pi^+\pi^0$	0.1	$p^+K_S^0\pi^0$	2.0		
K^-K^+	0.4			$p^+K_S^0\pi^+\pi^-$	1.6		
$K^-K^+\pi^0$	0.3			$\pi^+\pi^-\Sigma^+$	4.5		
$K^-K^+K_S^0$	0.4			$\pi^+\pi^-\pi^0\Sigma^+$	1.2		
$\pi^0K_S^0$	1.2			$\pi^0\Sigma^+$	1.2		
sum	53.1	sum	30.5	sum	28.2	sum	22.8

Table 1: D_{tag} decay channels (note : $\pi^+\pi^-\pi^0\Sigma^+$ not measured yet)

66 3.2.1 Preselection for final state particles

- 67 • Selection for charged tracks
 - 68 – $dr < 1.0$ and $|dz| < 3.0$ and thetaInCDCAcceptance
- 69 • PID selection for Charged hadrons (π^+ , K^+ and p^+)

- 70 – π^+ : 15 candidates with highest pionID after pionID > 0.01
 71 – K^+ : 10 candidates with highest kaonID after kaonID > 0.1
 72 – p^+ : 10 candidates with highest protonID after protonID > 0.1

 73 • selection for π^0 , K_S^0 , Σ^+ and Λ^0
 74 – K_S^0 : $0.468 \text{ GeV}/c^2 < M < 0.506 \text{ GeV}/c^2$ and goodBelleKshort == 1
 75 – Σ^+ : $1.08 \text{ GeV}/c^2 < M < 1.28 \text{ GeV}/c^2$
 76 – π^0 :
 77 * standard eff40 May2020 π^0
 78 * beamBackgroundSuppression > 0.5 and fakePhotonSuppression > 0.1 for
 79 each daughter γ
 80 – Λ^0 :
 81 * $1.111 \text{ GeV}/c^2 < M < 1.121 \text{ GeV}/c^2$
 82 * dr > 0.1
 83 * $\chi^2 < 100$
 84 * cosAngleBetweenMomentumAndVertexVectorInXYPlane > 0.99

85 **3.2.2 Preselection for D_{tag} candidate**

86 For D_{tag} reconstruction, I applied some selections on mass and momentum variables
 87 and if vertex fit was applied, selection on χ^2 . this is just preselection so just only some
 88 basic selections were applied such as roughly mass cut covering the nominal mass and
 89 selection on p^* for suppressiong charm particle from B meson decay and accept only
 90 reasonable scaled momentum(xp) value. the below table is about this preselection.

D^0	$1.81 \text{ GeV}/c^2 < M < 1.91 \text{ GeV}/c^2$ $p^* > 2.3 \text{ GeV}$ and $xp > 0.0$ $\chi^2 < 20$
D^+	$1.81 \text{ GeV}/c^2 < M < 1.91 \text{ GeV}/c^2$ $p^* > 2.3 \text{ GeV}$ and $xp > 0.0$ $\chi^2 < 20$
Λ_c^+	$2.23 \text{ GeV}/c^2 < M < 2.33 \text{ GeV}/c^2$ $p^* > 2.3 \text{ GeV}$ and $xp > 0.0$ $\chi^2 < 20$
D_s^+	$1.91 \text{ GeV}/c^2 < M < 2.0 \text{ GeV}/c^2$ $p^* > 2.3 \text{ GeV}$ and $xp > 0.0$ $\chi^2 < 20$
Note	selection about χ^2 is only on those reconstructed channels with vertex fit

Table 2: preselection for D_{tag} reconstruction

91 **3.3 D_{tag}^* reconstruction**

Table 3: D_{tag}^* decay channels

D^{*+} decay	Br(%)	D^{*0} decay	Br(%)	D_s^{*+} decay	Br(%)
$D^0\pi^+$	67.7	$D^0\pi^0$	61.9	$D_s^+\gamma$	93.5
$D^+\pi^0$	30.7	$D^0\gamma$	38.1		
sum	98.4	sum	100.0	sum	93.5

92 For reconstruction of D_{tag}^* , I used totally 5 channels listed in the table 3. in this step,
 93 π^0, π^\pm and γ are used for reconstruction and I also did π^0 veto to suppress background in
 94 case of using γ .

- 95 • Selection for π^\pm, π^0 and γ to reconstruct D_{tag}^*
 - 96 – π^\pm : same selection criteria with preselection on first step of charm tagger
 - 97 – π^0 : same selection criteria with preselection on first step of charm tagger
 - 98 – γ :
 - 99 * $|\text{clusterTiming}| < 200$ ns and $\left| \frac{\text{clusterTiming}}{\text{clusterErrorTiming}} \right| < 2.0$
 - 100 * $\text{beamBackgroundSuppression} > 0.5$ and $\text{fakePhotonSuppression} > 0.1$
 - 101 * $E > 0.1$ GeV
- 102 • Selection for π^0 veto on $D^{*0} \rightarrow D^0\gamma$ and $D_s^+ \rightarrow D_s^+\gamma$:
 - 103 The γ used in reconstruction of $D^{*0} \rightarrow D^0\gamma$ and $D_s^+ \rightarrow D_s^+\gamma$ can be from $\pi^0 \rightarrow \gamma\gamma$.
 104 so I would like to suppress background from $\pi^0 \rightarrow \gamma\gamma$ decay by vetoing γ candidate
 105 that can be from π^0 .

106 To do π^0 veto, the procedure is like this :

107 I made combination using γ_{sig} from $D^{*0} \rightarrow D^0\gamma$ and $D_s^+ \rightarrow D_s^+\gamma$
 108 and γ_{roe} in rest of event and check whether that combination is π^0 like
 109 by checking $M_{\gamma_{sig}\gamma_{roe}}$ and if that combination is in π^0 selection,
 110 then veto $D^{*0} \rightarrow D^0\gamma$ and $D_s^+ \rightarrow D_s^+\gamma$ candidates.

- 112 – γ_{roe} :
 - 113 * standard loose photon:
 114 inCDCAcceptance and $\text{clusterErrorTiming} < 10^6$
 115 $\text{clusterE1E9} > 0.4$ or $E > 0.075$
 - 116 * should be in Rest Of Event ($\text{isRestOfEvent} == 1$)
 - 117 * $\text{beamBackgroundSuppression} > 0.5$ and $\text{fakePhotonSuppression} > 0.1$
- 118 – π^0 (combination of γ_{sig} and γ_{roe}):
 - 119 * $0.115 \text{ GeV}/c^2 < M_{\gamma_{sig}\gamma_{roe}} < 0.150 \text{ GeV}/c^2$
 - 120 * $\left| \frac{E_{\gamma_1} - E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}} \right| < 0.5$
 - 121 * select one π^0 candidate with smallest dM

¹²² **3.3.1 Preselection for D_{tag}^* candidate**

Table 4: Selections of D_{tag}^*

D_{tag}^*	Mass [GeV/c ²]	ΔM [GeV/c ²]
$D^{*+} \rightarrow D^0\pi^+$	1.96 ~ 2.06	0.14 ~ 0.15
$D^{*+} \rightarrow D^+\pi^0$	1.96 ~ 2.06	0.1375 ~ 0.1465
$D^{*0} \rightarrow D^0\pi^0$	1.95 ~ 2.05	0.1375 ~ 0.1465
$D^{*0} \rightarrow D^0\gamma$	1.95 ~ 2.05	0.125 ~ 0.160
$D_s^{*+} \rightarrow D_s^+\gamma$	2.06 ~ 2.16	0.125 ~ 0.16
Note	xp > 0.0 for all D_{tag}^* vertex fit on $D^{*+} \rightarrow D^0\pi^+$	

¹²³ **3.4 FastBDT: background suppression from $D_{tag}^{(*)}$ reconstruct**

¹²⁴ Since there are so much $D_{tag}^{(*)}$ decay channels for tag side reconstruction, the mis-
¹²⁵ reconstructed $D_{tag}^{(*)}$ can be one of the main source of backgrounds. so I used fastBDT to
¹²⁶ suppress the background from reconstruction of $D_{tag}^{(*)}$. I totally trained 51 BDTs for D_{tag}
¹²⁷ and 5 BDTs for D_{tag}^* for this charm tagger.

¹²⁸ The training is done on 1ab⁻¹ MC15 run independent generic MC sample. in order
¹²⁹ to avoid bias in training, the size of signal and background sample for each trainings was
¹³⁰ set up as same.

¹³¹ **3.4.1 Input variables of FastBDT**

¹³² • Input variables for D_{tag} training

- ¹³³ – PID for charged tracks : pionID for π^+ , kaonID for K^+ , protonID for p^+
- ¹³⁴ – dr(flightlength), dz (these variables used for the decay with vertex fit applied)
- ¹³⁵ – Mass : M
- ¹³⁶ – scaled momentum : xp
- ¹³⁷ – angle variables :
 - ¹³⁸ * cosAngleBetweenMomentumAndVertexVectorInXYPlane
 - ¹³⁹ * cosToThrustOfEvent
 - ¹⁴⁰ * cosHelicityAngle(only for 2 body or 3 body decays)
- ¹⁴¹ – variables for π^0, K_S^0, Λ^0 and Σ^+ :
 - ¹⁴² * Energy Asymmetry between two daughters : $\left| \frac{E_{d_1} - E_{d_2}}{E_{d_1} + E_{d_2}} \right|$
 - ¹⁴³ * Angle between momentum of two daughters

¹⁴⁴ • Input variables for D_{tag}^* training

- ¹⁴⁵ – PID for charged tracks : pionID for π^+
- ¹⁴⁶ – momentum of γ
- ¹⁴⁷ – dr(flightlength), dz (these variables used for the decay with vertex fit applied)

- 148 – $\Delta M (=M_{D_{tag}^*} - M_{D_{tag}})$
- 149 – scaled momentum : xp
- 150 – angle variables :
 - 151 * cosAngleBetweenMomentumAndVertexVectorInXYPlane
 - 152 * cosToThrustOfEvent
 - 153 * cosHelicityAngle
- 154 – variables for π^0 :
 - 155 * Energy Asymmetry between two daughters : $\left| \frac{E_{\gamma_1} - E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}} \right|$
 - 156 * Angle between momentum of two daughters

157 3.4.2 BDT Input variable distribution

158 In this section, there are BDT input variables for training about $D^0 \rightarrow \pi^+ \pi^- K_S^0$ in
 159 tag side. All the other training informations will be appendix section.

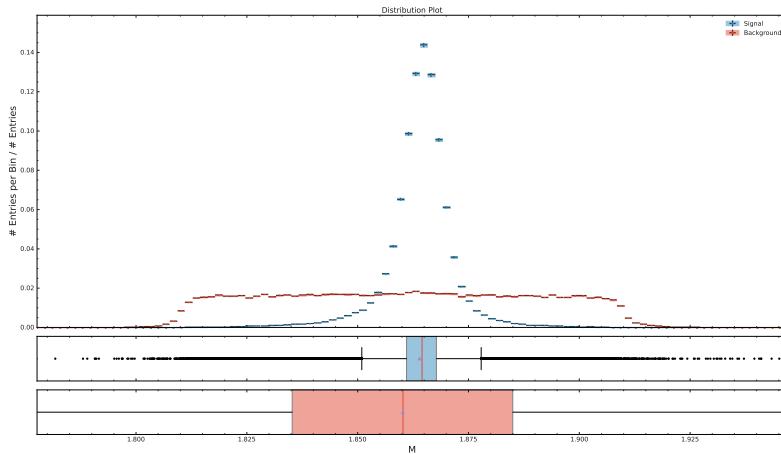


Figure 4: BDT Input variable: Mass

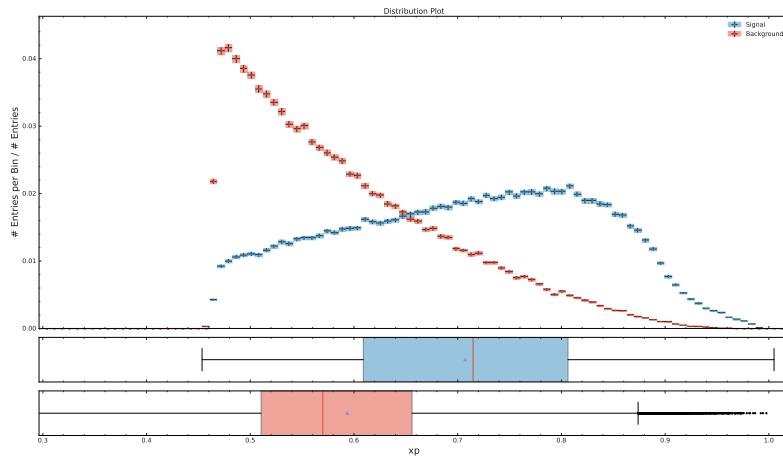


Figure 5: BDT Input variable: xp (scaled momentum)

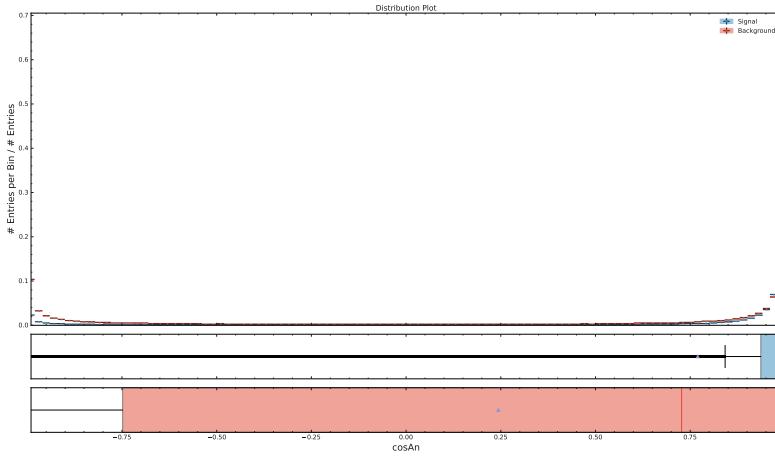


Figure 6: BDT Input variable: $\text{cosAngleBetweenMomentumAndVertexVectorInXYPlane}$

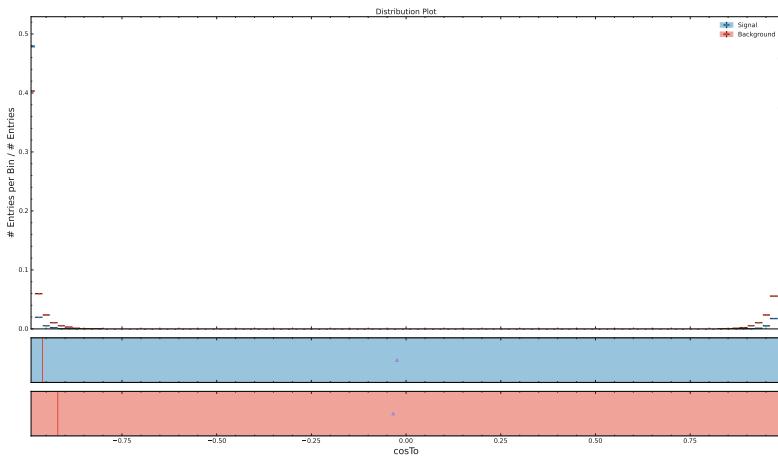


Figure 7: BDT Input variable: $\text{cosToThrustOfEvent}$

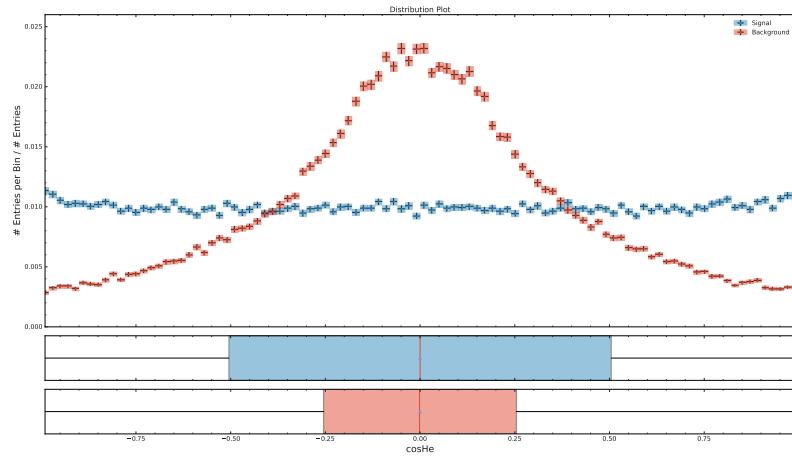


Figure 8: BDT Input variable: $\text{cosHelicityAngleMomentum}$

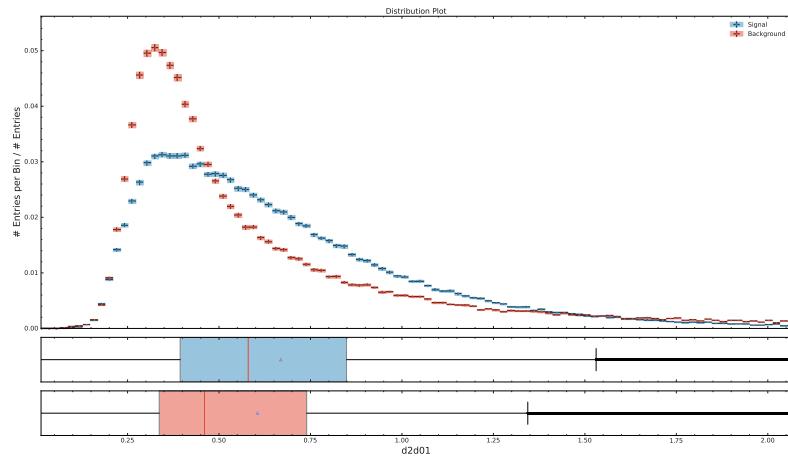


Figure 9: BDT Input variable: angle between 2 daughters of K_S^0

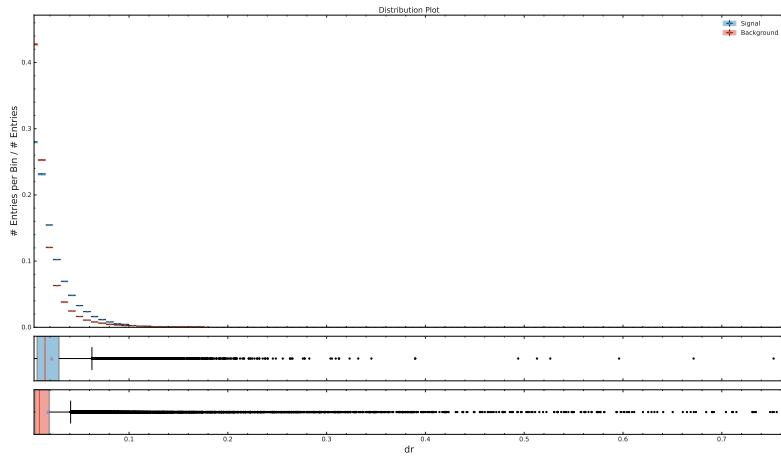


Figure 10: BDT Input variable: dr

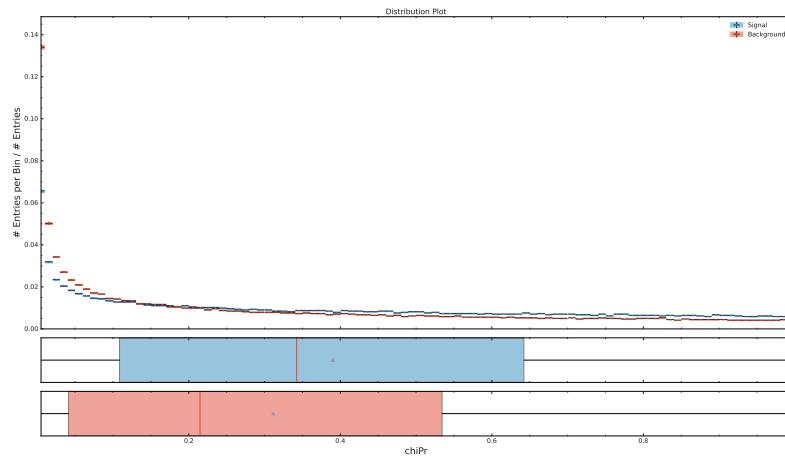


Figure 11: BDT Input variable: chiProb

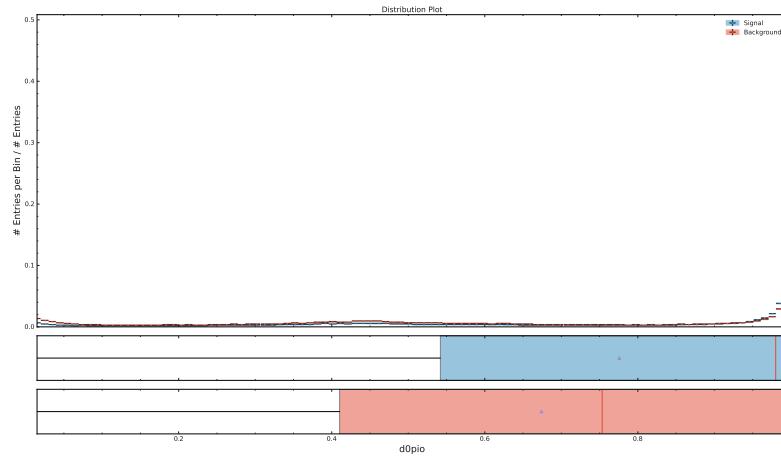


Figure 12: BDT Input variable: pionID

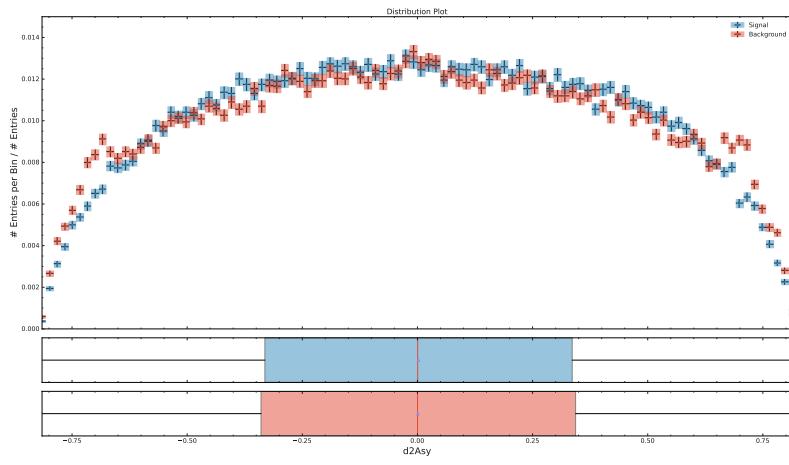


Figure 13: BDT Input variable: Energy Asymmetry

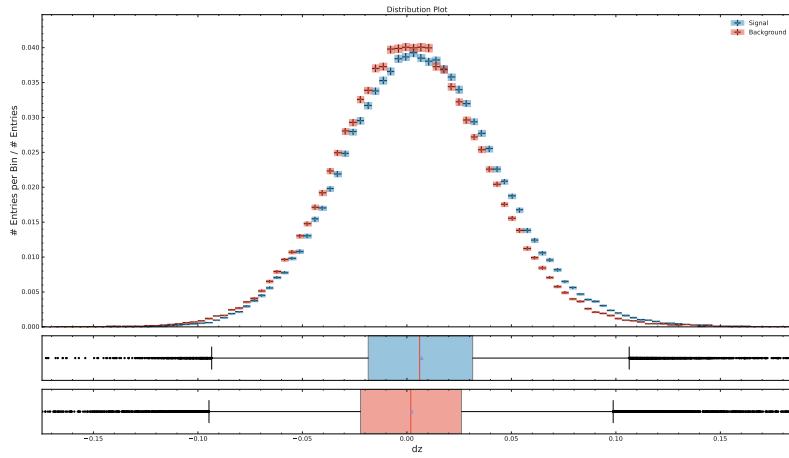


Figure 14: BDT Input variable: dz

160 3.4.3 Check correlation on BDT Input variables

161 As first trial, as many variables as possible are used for BDT input variables and then
 162 with checking correlation and importance of variables some variables are removed in BDT
 163 input variable lists.

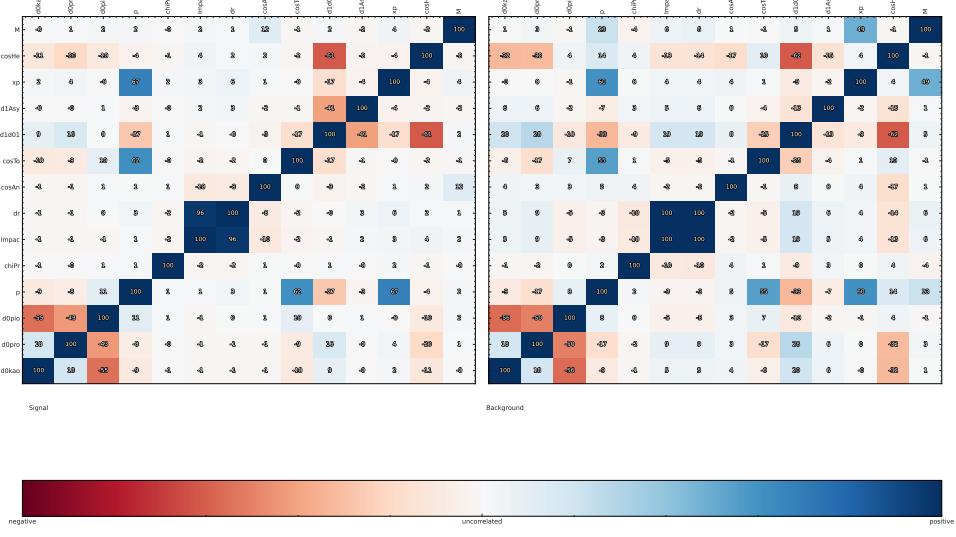


Figure 15: high correlation in old training $\Lambda_c^+ \rightarrow p^+ K_S^0 \pi^0$



Figure 16: importance of BDT variables of training $\Lambda_c^+ \rightarrow p^+ K_S^0 \pi^0$

164 All the pionID, kaonID and protonID for each pion, kaon and proton candidate were
 165 used in training, but it seems not so worthwhile but just had correlations each variables. so
 166 the PID variables are reduced by removing redundant kaonID, protonID for pion candidate
 167 and pionID, protonID for kaon candidate and pionID, kaonID for proton candidate. In
 168 case of high correlation above 50 commonly in many tag channels, variables with low

importance are removed. For example, there were high correlation over Q, E, p, xp variables and xp had greater importance so Q, E, p are removed in BDT input variables.

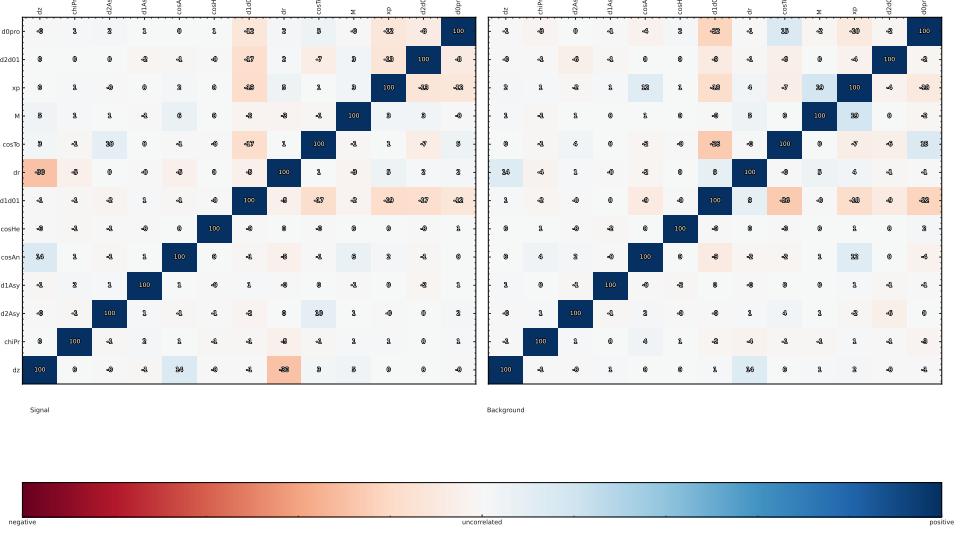


Figure 17: correlation plot in new training $\Lambda_c^+ \rightarrow p^+ K_S^0 \pi^0$

3.4.4 Optimizations of FastBDT setup and selection on FastBDT output

There are hyper parameters in BDT such as number of trees, cuts and depth. so I also optimized those hyper parameter by doing grid search about those parameters for each BDTs.

Another optimization is about the selection on BDT output. it is by calculating the Fom(Figure of Merit). the definition of Fom is $\frac{S}{\sqrt{S+B}}$.

These optimizations are done on all 56 BDTs.

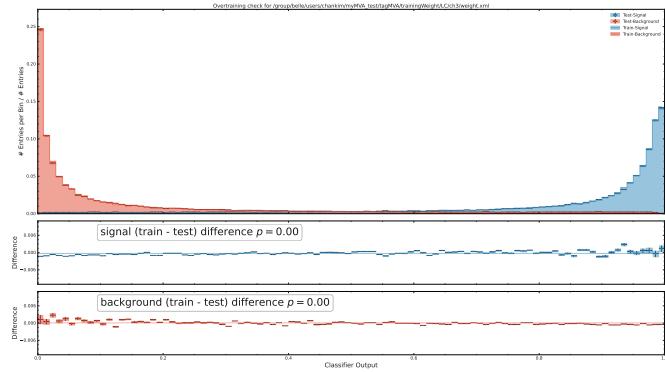


Figure 18: training result $\Lambda_c^+ \rightarrow p^+ K^- \pi^+ \pi^0$ as example

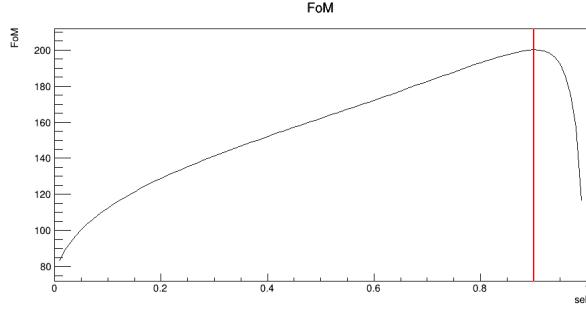


Figure 19: optimization on BDT output for $\Lambda_c^+ \rightarrow p^+ K^- \pi^+ \pi^0$ as example

¹⁷⁸ 3.5 X_{frag} reconstruction

Table 5: Fragmentation according to tag side

$D^{*+} \text{ or } D^+$	$D^{*0} \text{ or } D^0$	Λ_c^+	$D_s^{*+} \text{ or } D_s^+$
nothing($K^+ K^-$)	$\pi^+(K^+ K^-)$	$\pi^+ \bar{p}$	K_S^0
$\pi^0(K^+ K^-)$	$\pi^+ \pi^0(K^+ K^-)$	$\pi^+ \pi^0 \bar{p}$	$\pi^0 K_S^0$
$\pi^+ \pi^-(K^+ K^-)$	$\pi^+ \pi^+ \pi^-(K^+ K^-)$	$\pi^+ \pi^- \pi^+ \bar{p}$	$\pi^+ K^-$
$\pi^+ \pi^- \pi^0(K^+ K^-)$			$\pi^+ \pi^- \pi^0 K_S^0$
			$\pi^+ K^-$
			$\pi^+ \pi^0 K^-$
			$\pi^+ \pi^- \pi^+ K^-$

¹⁷⁹ All fragmentation channels are selected with conserving baryon quantum number and
¹⁸⁰ strangeness quantum number and charge according to $D_{tag}^{(*)}$ particle so that the signal side
¹⁸¹ can contain $D^{*\pm}$. Totally 24 channels are used as fragmentations and listed in table 5.

¹⁸² 3.5.1 Preselection for X_{frag}

- ¹⁸³ Selection for fragmentation particles (π^+ , K^+ and p^+ and π^0)
 - ¹⁸⁴ π^+ : pionID > 0.1 and p > 0.1 GeV
 - ¹⁸⁵ K^+ : kaonID > 0.9 and p > 0.1 GeV
 - ¹⁸⁶ p^+ : protonID > 0.9 and p > 0.1 GeV
 - ¹⁸⁷ K_S^0 : same with K_S^0 in charm tagger with p > 0.1 GeV
 - ¹⁸⁸ π^0 :
 - ¹⁸⁹ * same with preselection of π^0 in charm tagger
 - ¹⁹⁰ * additionally p > 0.1 GeV
 - ¹⁹¹ * additionally $\left| \frac{E_{\gamma_1} - E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}} \right| < 0.9$

¹⁹² 3.6 Reconstruction of signal side D^*

¹⁹³ There are many possible combinations in X_{frag} and it means there can be many
¹⁹⁴ backgrounds from possible combination of particles in fragmentation. so I applied inverse

195 mass constrained fit on $M_{miss}(D_{tag}^{(*)}X_{frag})$ to m_{D^*} , the nominal mass of $D^{*\pm}$, and choose
 196 only one candidate with highest chiProb calculated from this mass constrained fit.

197 3.7 Reconstruction of signal side D^0 from recoiled $D^{*\pm}$

198 With tagging π_s^+ , singal D^0 momentum is calculated by $p_{miss}(D_{tag}^{(*)}X_{frag}) - p(\pi_s^+)$.
 199 one thing to be careful is that there can be also multiple candidates from multiple π_s^+
 200 candidates. so I choosed one recoiled signal side D^0 with largest opening angle between
 201 momentums of $D_{tag}^{(*)}$ and signal side D^0 in center of mass frame.

202 3.8 Charm tagger execution

- 203 • Procedure of Charm Tagger execution
 - 204 – Preparation of $\pi^+, K^+, p^+, \pi^0, K_S^0, \Lambda^0, \Sigma^+$
 - 205 – Reconstruction of D_{tag} with tag side decay channels
 - 206 – Optimized selection with FOM on BDT output about D_{tag}
 - 207 – Reconstruction of D_{tag}^*
 - 208 – Optimized selection with FOM on BDT output about D_{tag}^*
 - 209 – Reconstruction recoiled signal side $D^{*\pm}$ with $D_{tag}^{(*)}$ and X_{frag}
 - 210 – inverse mass constrained fit on recoiled signal side $D^{*\pm}$ mass
 - 211 – Selection of best candidate of recoiled signal side $D^{*\pm}$ with chiProb
 - 212 – Reconstruction of recoiled signal side D^0 with tagging π_s^\pm
 - 213 – Selection of best canadiate of recoiled signal side D^0 with opening angle be-
 214 between D_{tag}^* and recoiled signal D^0 in center of mass frame

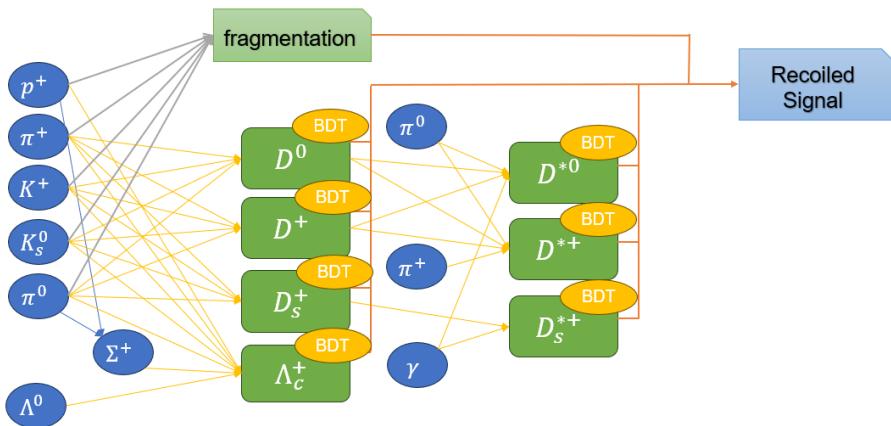


Figure 20: Scheme of Charm tagger execution

215 **3.9 D^0 from charm tagger**

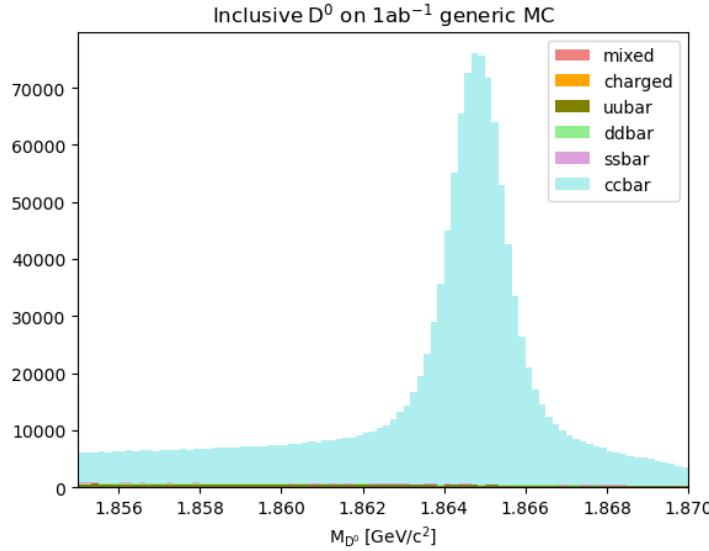


Figure 21: Recoiled signal D^0 from charm tagger on 1ab^{-1} generic MC

- 216 • Inclusive D^0 : D^0 from charm tagger can have any decays since there are no require-
217 ments on signal side. so D^0 from charm tagger is inclusive D^0 .
 - 218 – tagging efficiency: 0.18%
- 219 • Exclusive D^0 : exclusive D^0 from charm tagger is subset of inclusive D^0 from charm
220 tagger by requiring some selections on the signal side(=rest of event of $D_{tag}^{(*)} X_{frag} \pi_s^\pm$).
221 For this, I checked number of tracks, $\pi^0, K_S^0, K_L^0, \Lambda^0$, and if possilbe, directly recon-
222 structed signal D^0 .
 - 223 – track selection : $\text{dr} < 1.0$ and $|\text{dz}| < 3.0$
 - 224 – K_S^0 selection : same with tag preselection
 - 225 – Λ^0 selection : same with tag preselection
 - 226 – π^0 selection :
 - 227 * $0.115 \text{ GeV}/c^2 < M < 0.155 \text{ GeV}/c^2$
 - 228 * $|\text{clusterTiming}| < 200 \text{ ns}$ and $\left| \frac{\text{clusterTiming}}{\text{clusterErrorTiming}} \right| < 2.0$ for daughter γ
 - 229 * $\text{beamBackgroundSuppression} > 0.5$ and $\text{fakePhotonSuppression} > 0.1$ for
230 daughter γ
 - 231 – K_L^0 selection :
 - 232 * $0.468 \text{ GeV}/c^2 < M < 0.508 \text{ GeV}/c^2$ and $0.5 \text{ GeV} < E < 10.0 \text{ GeV}$
 - 233 * $\text{klmClusterKlId} > 0.2$ and $\text{nKLMClusterTrackMatches} == 0$

234 4 Skimming

235 Skim is needed for efficient data use since the data size is very huge. so, there are
236 some skim selections such as cuts on PID and mass and momentum variables that are
237 covering the selections in step of reconstruction.

- 238 • Selection for charged tracks on skim
 - 239 – $dr < 1.0$ and $|dz| < 3.0$ and thetaInCDCAcceptance
- 240 • PID selection for Charged hadrons (π^+ , K^+ and p^+)
 - 241 – π^+ : 15 candidates with highest pionID after pionID > 0.01
 - 242 – K^+ : 10 candidates with highest kaonID after kaonID > 0.1
 - 243 – p^+ : 10 candidates with highest protonID after protonID > 0.1
- 244 • selection for π^0 , K_S^0 , Σ^+ and Λ^0 on skim
 - 245 – K_S^0 : $0.468 \text{ GeV}/c^2 < M < 0.506 \text{ GeV}/c^2$ and goodBelleKshort == 1
 - 246 – Σ^+ : $1.08 \text{ GeV}/c^2 < M < 1.28 \text{ GeV}/c^2$
 - 247 – π^0 :
 - 248 * $0.115 \text{ GeV}/c^2 < M < 0.160 \text{ GeV}/c^2$
 - 249 * $E > 0.05 \text{ GeV}$ for daughter γ
 - 250 – Λ^0 :
 - 251 * $1.111 \text{ GeV}/c^2 < M < 1.121 \text{ GeV}/c^2$
 - 252 * $dr > 0.1$ and $\chi^2 < 100$
 - 253 * cosAngleBetweenMomentumAndVertexVectorInXYPlane > 0.99
- 254 • Skim selection for tag side D^0 : $1.72 \text{ GeV}/c^2 < M < 2.02 \text{ GeV}/c^2$ and $p^* > 2.0 \text{ GeV}$
- 255 • Skim selection for tag side D^+ : $1.72 \text{ GeV}/c^2 < M < 2.02 \text{ GeV}/c^2$ and $p^* > 2.0 \text{ GeV}$
- 256 • Skim selection for tag side D_s^+ : $1.82 \text{ GeV}/c^2 < M < 2.12 \text{ GeV}/c^2$ and $p^* > 2.0 \text{ GeV}$
- 257 • Skim selection for tag side Λ_c^+ : $2.18 \text{ GeV}/c^2 < M < 2.38 \text{ GeV}/c^2$ and $p^* > 2.0 \text{ GeV}$
- 258 • Skim selection for $D^{*+} \rightarrow D^0\pi^+$: $0.135 \text{ GeV}/c^2 < \Delta M < 0.155 \text{ GeV}/c^2$
- 259 • Skim selection for $D^{*+} \rightarrow D^+\pi^0$: $0.130 \text{ GeV}/c^2 < \Delta M < 0.160 \text{ GeV}/c^2$
- 260 • Skim selection for $D^{*0} \rightarrow D^0\pi^0$: $0.130 \text{ GeV}/c^2 < \Delta M < 0.160 \text{ GeV}/c^2$
- 261 • Skim selection for $D^{*0} \rightarrow D^0\gamma$: $0.120 \text{ GeV}/c^2 < \Delta M < 0.165 \text{ GeV}/c^2$
- 262 • Skim selection for $D_s^{*+} \rightarrow D_s^+\gamma$: $0.120 \text{ GeV}/c^2 < \Delta M < 0.165 \text{ GeV}/c^2$
- 263 • Skim selection for signal side $D^{*\pm}$ and D^0
 - 264 – $1.81 \text{ GeV}/c^2 < M_{D^*} < 2.21 \text{ GeV}/c^2$ for signal side $D^{*\pm}$
 - 265 – $0.08 \text{ GeV}/c^2 < M_{D^*} - M_{D^0} < 0.27 \text{ GeV}/c^2$ and $p^* > 2.0 \text{ GeV}$ for signal D^0

266 **5 Signal extraction**

267 For signal extraction, I used recoil mass(M_{D^0}) for extraction of signal yield of inclusive
 268 D^0 and also used both of recoil mass(M_{D^0}) and extra remained energy in ECL (E_{ECL})
 269 for extraction of signal yield of exclusive D^0 .

270 About E_{ECL} calculation, some constraints are applied to remove cluster energy from
 271 beam background.

- 272 • $|\text{clusterTiming}| < 200 \text{ ns}$ and $\left| \frac{\text{clusterTiming}}{\text{clusterErrorTiming}} \right| < 2.0$ for γ
- 273 • $\text{beamBackgroundSuppression} > 0.5$ and $\text{fakePhotonSuppression} > 0.1$ for γ
- 274 • $\text{dr} < 1.0$ and $|\text{dz}| < 3.0$ for e^-
- 275 • $\text{electronID} > 0.6$ for e^-
- 276 • $\text{isFromECL} > 0$ and $\text{isRestOfEvent} == 1$ for γ and e^-

277 **5.1 Fit strategy**

278 1D fit on M_{D^0} and 2D fit on (M_{D^0}, E_{ECL}) were performed for signal extraction of
 279 inclusive or exclusive D^0 . the fit region is $1.855 \text{ GeV}/c^2 < M_{D^0} < 1.870 \text{ GeV}/c^2$ for
 280 inclusive D^0 fit and $1.855 \text{ GeV}/c^2 < M_{D^0} < 1.870 \text{ GeV}/c^2$ and $E_{ECL} < 2.1 \text{ GeV}$ for
 281 exclusive D^0 fit.

- 282 • each component PDF about M_{D^0} for inclusive D^0 :
 - 283 – signal PDF on M_{D^0} : combination of 2 gaussians and 1 bifurcated gaussian with
 284 same mean
 - 285 Note : The signal PDF shape is fixed on fit result about $D^0 \rightarrow \nu\bar{\nu}$ signal MC
 - 286 – background PDF on M_{D^0} : combination of argus and linear function
- 287 • each component PDF about M_{D^0} for exclusive D^0 :
 - 288 – signal PDF on M_{D^0} : signal PDF from Inclusive D^0 fit
 - 289 – flat background PDF on M_{D^0} : combination of argus and linear function
 - 290 – peak background PDF on M_{D^0} : 3 gaussians with same mean
- 291 • each component PDF about E_{ECL} for exclusive D^0 :
 - 292 – signal PDF: histogram PDF from exclusive D^0 on signal MC
 - 293 – flat background PDF: histogram PDF from sideband on background only MC
 294 sideband: $1.855 \text{ GeV}/c^2 < M_{D^0} < 1.870 \text{ GeV}/c^2$
 - 295 – peak background PDF:
 - 296 * (a) : histogram PDF in peak region
 297 peak region: $1.860 \text{ GeV}/c^2 < M_{D^0} < 1.870 \text{ GeV}/c^2$
 - 298 * (b) : histogram PDF in sideband
 - 299 * peak background histogram PDF = $(1 + w)^*(a) - w^*(b)$
 (w: floating variable between 0 and 1)

301 **5.1.1 Inclusive D^0**

For signal extraction of inclusive D^0 , one-dimensional extended binned maximum likelihood fit is performed on the recoil mass($M_{D^0} \equiv M_{miss}(D_{tag}^{(*)} X_{frag} \pi_s^\pm)$). Fit is performed with maximizing this likelihood function defined as

$$L = \frac{e^{-\sum_j N_j}}{N!} \prod_{i=1}^N (\Sigma_j N_j P_j(M_{D^0}^i)),$$

302 The N is total number of candidates, N_j is the number of events in component j ,
 303 $M_{D^0}^i$ is M_{D^0} value of i -th candidate and P_j is one-dimensinal probability density function
 304 corresponding to the j component.

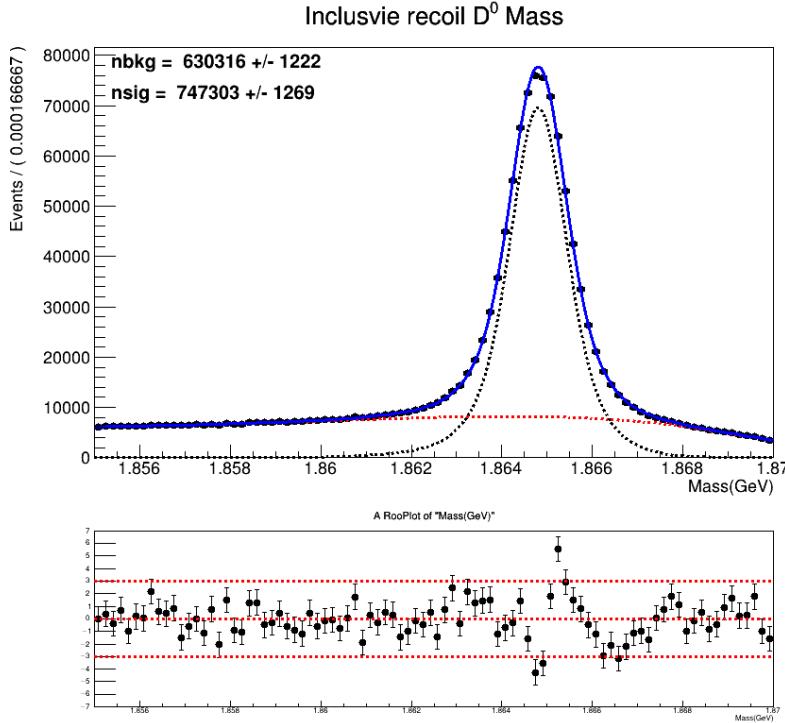


Figure 22: fit result of inclusive D^0 on 1ab^{-1} generic MC

305 **5.1.2 Exclusive D^0**

306 For signal extraction of exclusive D^0 , two-dimensional extended binned maximum
 307 likelihood fit is performed on (M_{D^0}, E_{ECL}) . two dimensional likelihood function is defined
 308 as

$$L = \frac{e^{-\sum_j N_j}}{N!} \prod_{i=1}^N (\Sigma_j N_j P_j(M_{D^0}, E_{ECL}))$$

309 N is total number of events in this fit, i means i -th candidate and P_j is probability
 310 density function of j component such as signal or flat background or peak background.

311 **6 $D^0 \rightarrow \nu\bar{\nu}$**

312 **6.1 Selection criterion for $D^0 \rightarrow \nu\bar{\nu}$**

- 313 • Exclusive selection for $D^0 \rightarrow \nu\bar{\nu}$ signal MC:
 314 no remaining tracks, $\pi^0, K_S^0, K_L^0, \Lambda^0$ in signal side

315 **6.2 Signal MC study: signal efficiency**

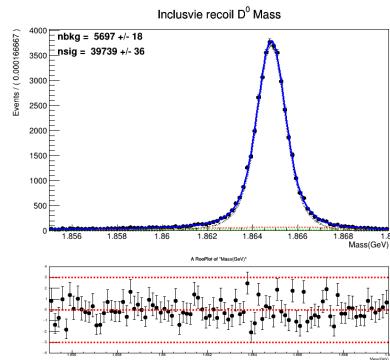


Figure 23: inclusive D^0 on signal MC

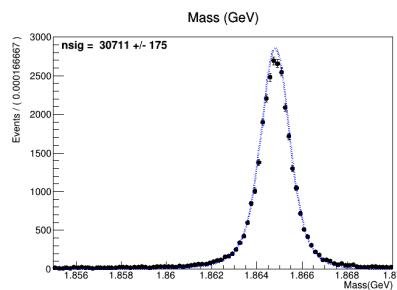


Figure 24: M_{D^0} of exclusive D^0 on signal MC

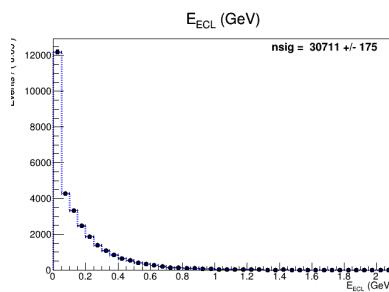


Figure 25: E_{ECL} of exclusive D^0 on signal MC

- 316 • signal efficiency : 0.77282 ± 0.00446

317 **6.3 2D fit result about $D^0 \rightarrow \nu\bar{\nu}$**

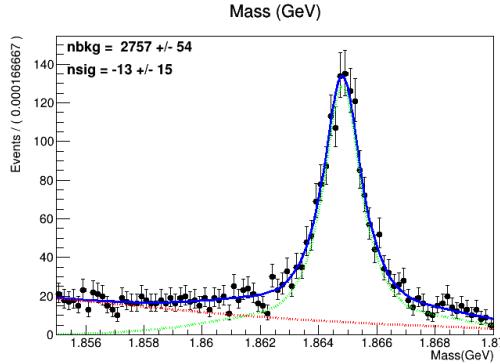


Figure 26: M_{D^0} of exclusive D^0 on generic MC

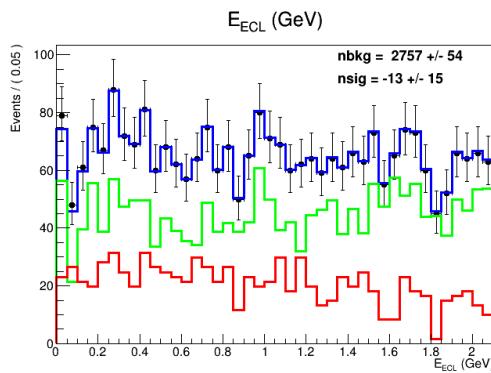


Figure 27: E_{ECL} of exclusive D^0 on generic MC

318 **7 Control Sample study : validation of charm tagger**

319 Following this analysis procedure, it is also possible to measure branching fraction of
 320 other decay. so, I tried to measure $\text{Br}(D^0 \rightarrow K^-\pi^+)$ with this charm tagger on purpose
 321 of validation of charm tagger.

322 **7.1 Selection criterion for $D^0 \rightarrow K^-\pi^+$**

- 323 • 2 remaining tracks and no $\pi^0, K_S^0, K_L^0, \Lambda^0$ in signal side
- 324 • 1 directly reconstructed $D^0 \rightarrow K^-\pi^+$ in signal side
 - 325 – selection for K^+ : kaonID > 0.6 and electronID < 0.95 and muonID < 0.95
 - 326 – selection for π^+ : pionID > 0.4 and electronID < 0.95 and muonID < 0.95
 - 327 – $1.80 \text{ GeV}/c^2 < M < 1.92 \text{ GeV}/c^2$

- 328 – vertex fit applied and choose one candidate with highest chiProb
 329 • $|\Delta E(\text{recoiled } E_{D^0} - E_{K\pi})| < 0.1 \text{ GeV}$

330 **7.2 Signal efficiency**

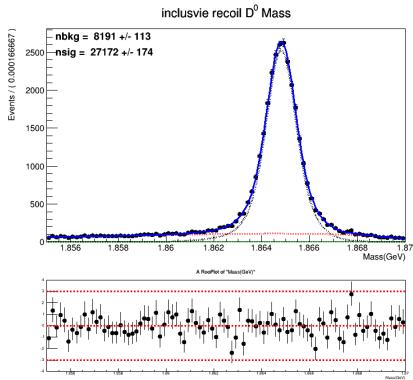


Figure 28: inclusive D^0 on $D^0 \rightarrow K^-\pi^+$ signal MC

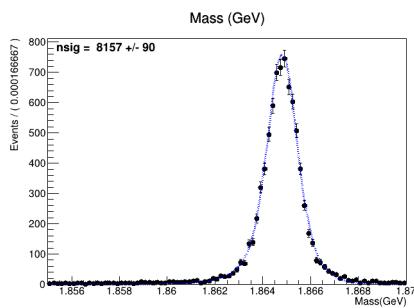


Figure 29: M_{D^0} of exclusive D^0 on $D^0 \rightarrow K^-\pi^+$ signal MC

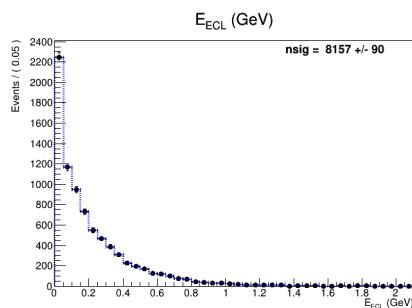


Figure 30: E_{ECL} of exclusive D^0 on $D^0 \rightarrow K^-\pi^+$ signal MC

- 331 • signal efficiency : 0.30020 ± 0.00383

332 **7.3 Measurement of $\text{Br}(D^0 \rightarrow K^-\pi^+)$**

333 The branching fraction calculation is based on this formula:

334

$$\text{Br}(D^0 \rightarrow K^-\pi^+) = \frac{N_{sig}^{excl}}{N_{sig}^{incl} \times \epsilon_{sig}}$$

335 N_{sig}^{incl} is signal yield of inclusive D^0 on generic MC and N_{sig}^{excl} is signal yield of exclusive
 336 $D^0 \rightarrow K^-\pi^+$ on generic MC and ϵ_{sig} is signal efficiency calculated on $D^0 \rightarrow K^-\pi^+$ signal
 337 MC study.

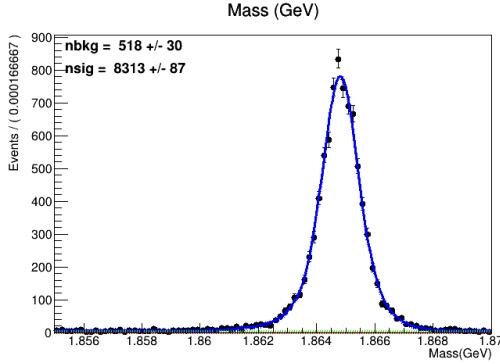


Figure 31: M_{D^0} of exclusive $D^0 \rightarrow K^-\pi^+$ on generic MC

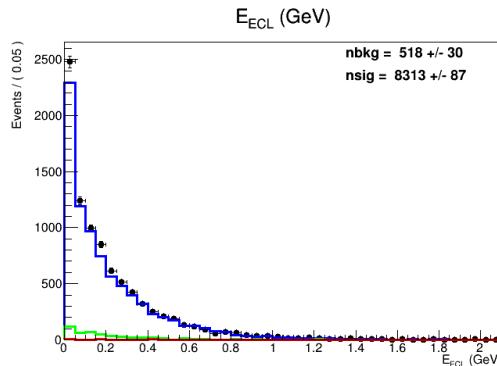


Figure 32: E_{ECL} of exclusive $D^0 \rightarrow K^-\pi^+$ on generic MC

338 based on these fit results, the measured $\text{Br}(D^0 \rightarrow K^-\pi^+)$ is 0.03706 ± 0.00061 .

339 **8 ToyMC study : check the stability of fitter**

340 Checking the fit result with pull distribution, almost fit results seems okay, but the
 341 inclusive D^0 fit result on generic MC shows a few points are out of 3σ range. so, Toy
 342 ensemble test and Linearity test are performed on this fit result. the bias from these tests
 343 will be considered as systematic uncertainty in future.

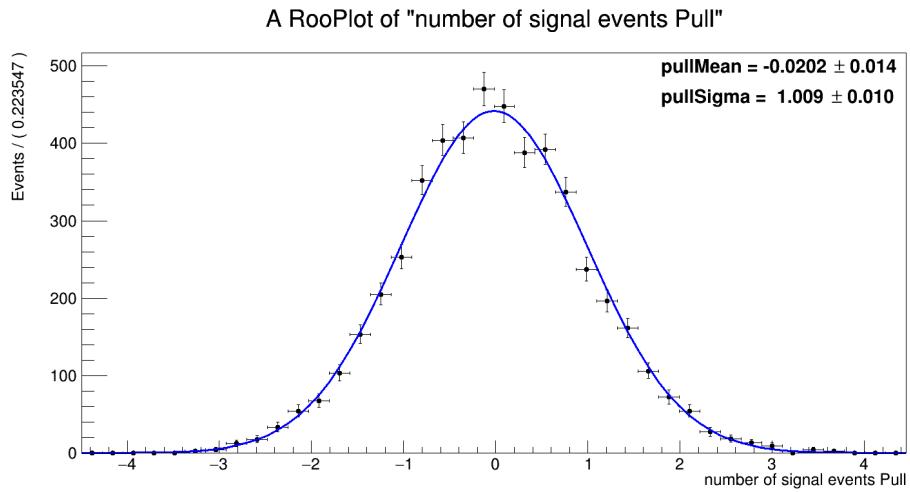


Figure 33: Toy ensemble test about N_{sig} on inclusive D^0 fit result on generic MC

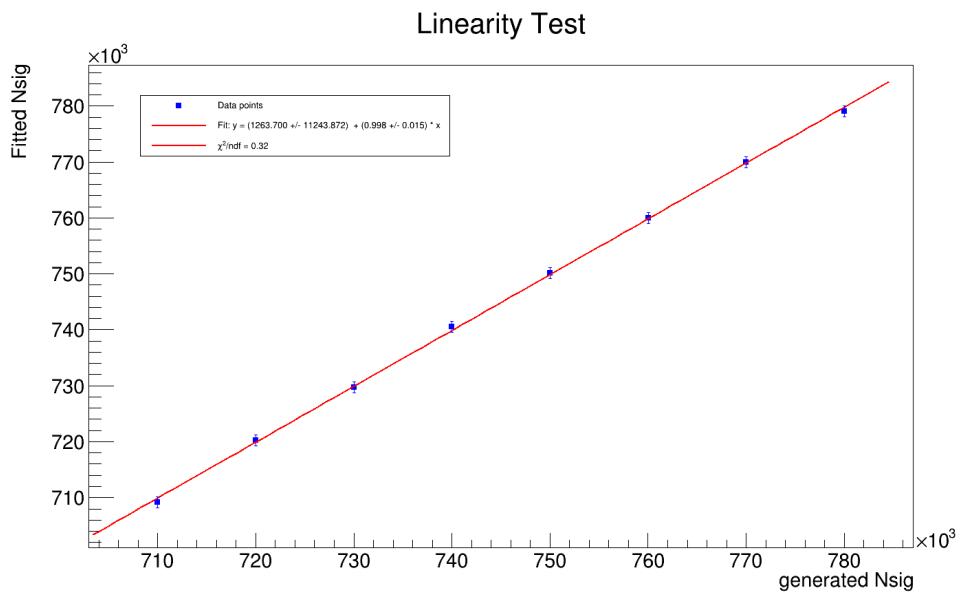


Figure 34: Linearity test about N_{sig} on inclusive D^0 fit result on generic MC

³⁴⁴ **9 Systematic uncertainties**

- ³⁴⁵ ● Charm tagger: tagging efficiency
- ³⁴⁶ ● Number of Inclusive D^0
- ³⁴⁷ ● Fit bias
- ³⁴⁸ ● Signal PDF
- ³⁴⁹ ● Flat background PDF
- ³⁵⁰ ● Peak background PDF
- ³⁵¹ ● Reconstruction efficiency uncertainty
- ³⁵² ● Veto on remaining detector information (tracks, π^0 , K_S^0 , K_L^0 , Λ^0)
- ³⁵³ ● Study veto efficiency dependence on $D_{tag}^{(*)}/X_{frag}$

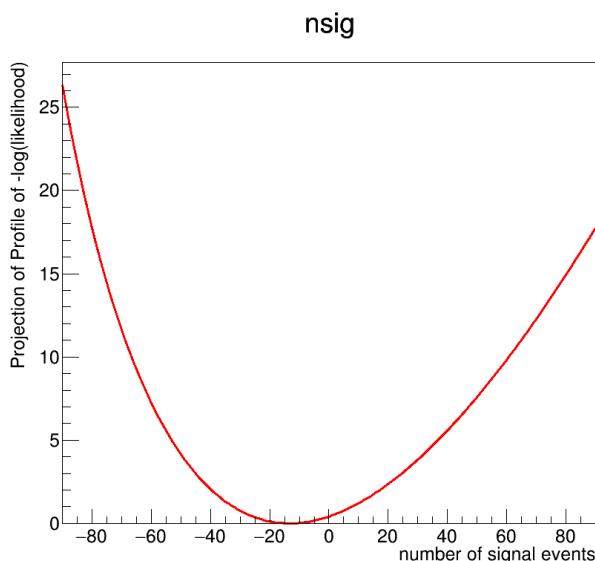
354 10 Upper Limit estimation

355 Since $D^0 \rightarrow \nu\bar{\nu}$ does not exist in generic MC, the signal yield should be zero. As
 356 shown in the figure 12 and figure 13, the signal yield from fit is consistent with the zero
 357 yield within 1σ . so, estimation of 90% Upper limit of Branching fraction was tried with
 358 2 methods. one is bayesian approach and the other is frequentist approach.

359
 360 Bayesian approach is based integrating the likelihood function shown below:

$$361 \int_0^N \mathcal{L}(n) dn = 0.9 \int_0^\infty \mathcal{L}(n) dn,$$

362 where $\mathcal{L}(n)$ is likelihood of fit result with condition that the number of signal yield is
 363 fixed at n. the systematic uncertainty is not considered yet. it will be included in future.



364 Figure 35: Negative log likelihood function

365 the estimated upper limit from bayesian approach is 2.0×10^{-5} .

366 Another method is frequentist approach which is called as CLs method. this calcula-
 367 tion is by RooStat Profile likelihood calculator based on frequentist statistics. The plot
 368 shows p-value of background only hypothesis(CL_b) as function of signal yield(N_{sig}) and
 369 signal+background(CL_{s+b}) and $CL_s (\equiv CL_{s+b}/CL_b)$ model. the colored area shows one
 370 and two σ expected CL_s value around the median value(black dashed line), asuuming
 371 data corresponds to the background only hypothesis.

372
 373 the estimated upper limit from this frequentist approach is 3.8×10^{-5} .

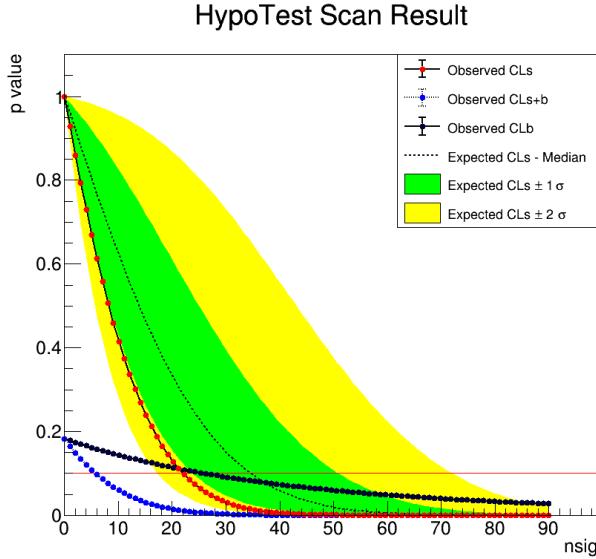


Figure 36: p-Value vs N_{sig} for CLs method

375 Appendices

376 A.1 BDT of Charm Tagger result

377 This section contains the BDT result.

378 A.1.1 $D^0 \rightarrow K^-\pi^+$

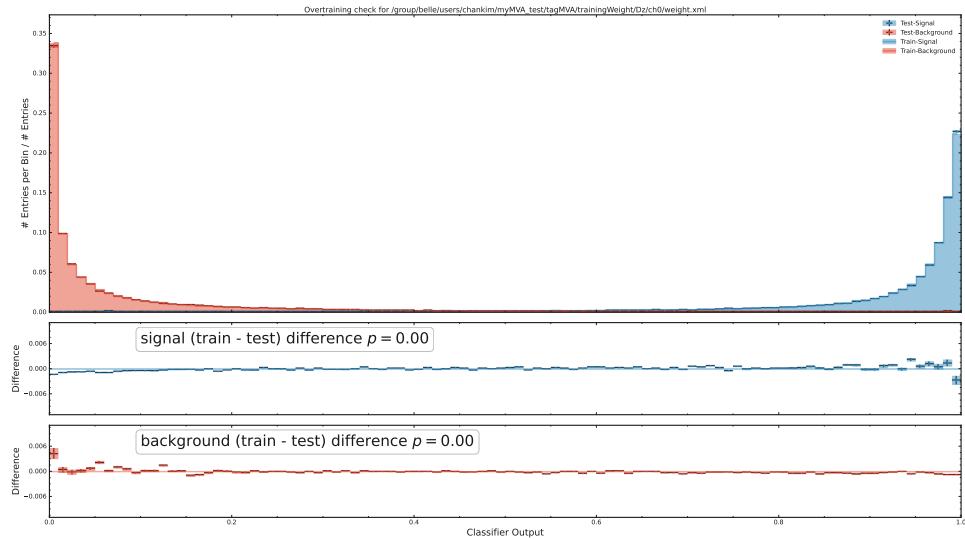


Figure 37: BDT output

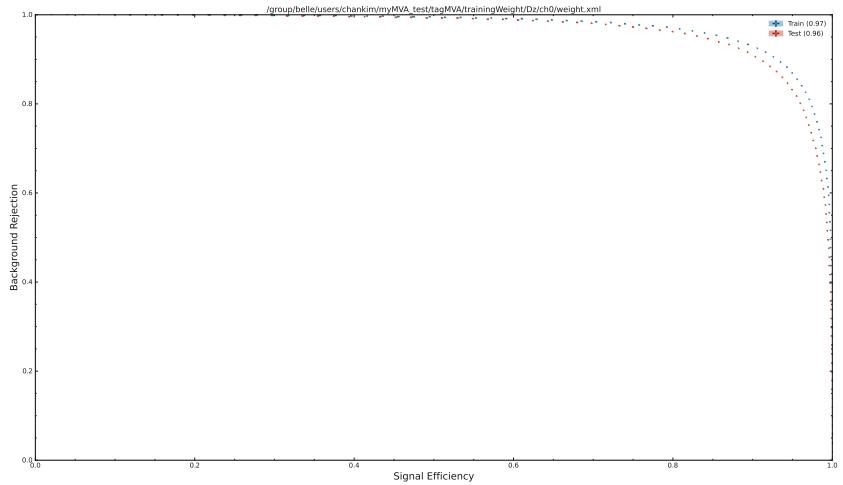


Figure 38: ROC Curve

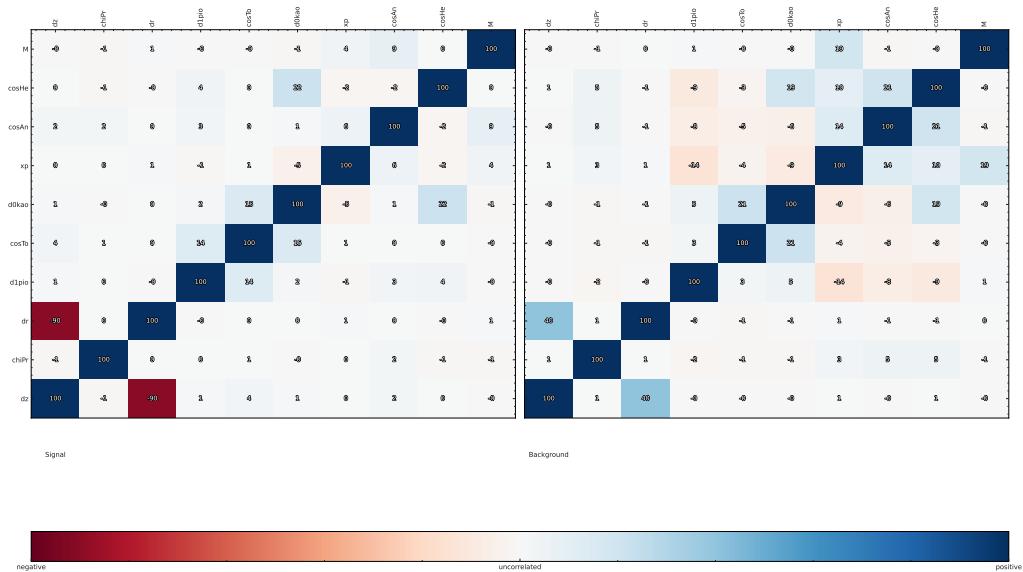


Figure 39: Correlation plot

379 **A.1.2** $D^0 \rightarrow K^- \pi^+ \pi^0$

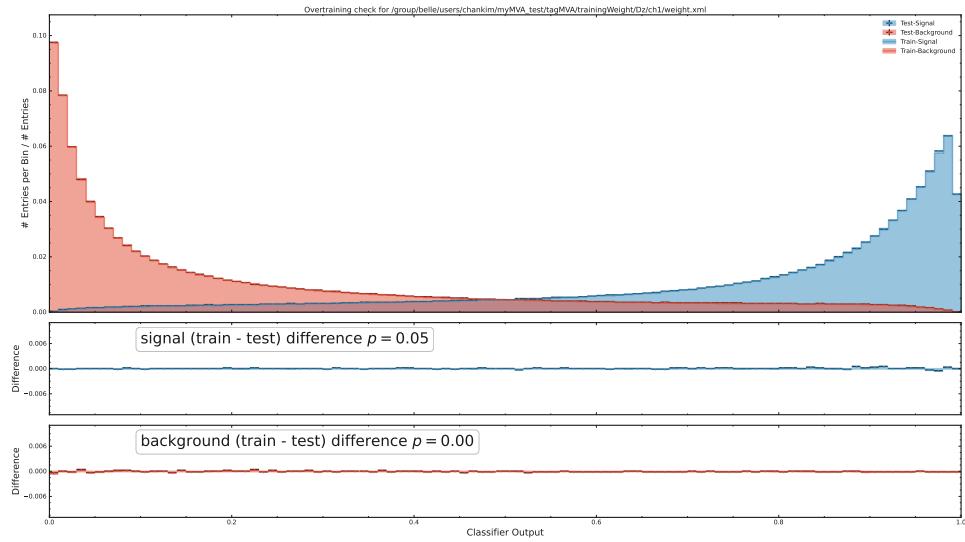


Figure 40: BDT output

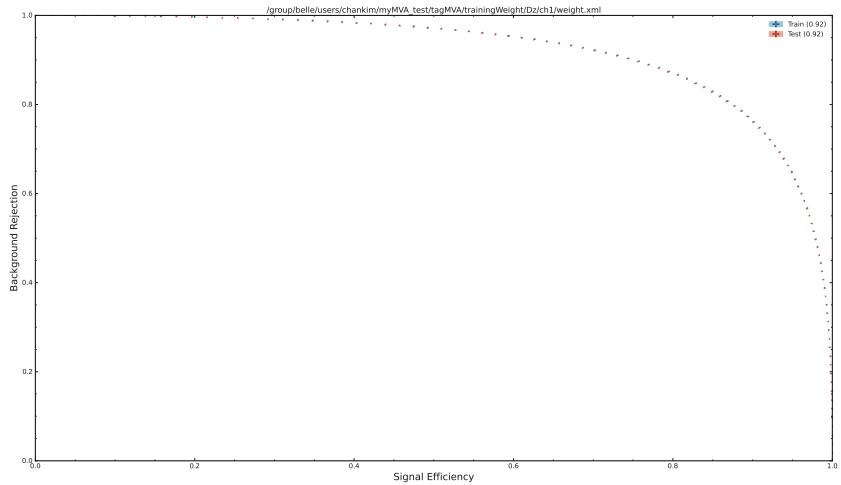


Figure 41: ROC Curve

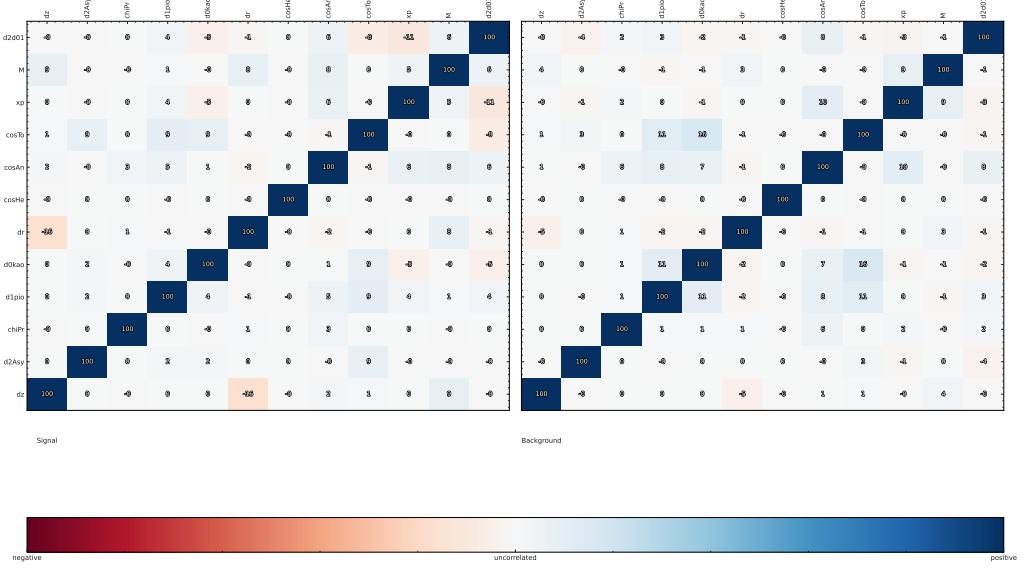


Figure 42: Correlation plot

380 A.1.3 $D^0 \rightarrow K^- \pi^+ \pi^0 \pi^0$

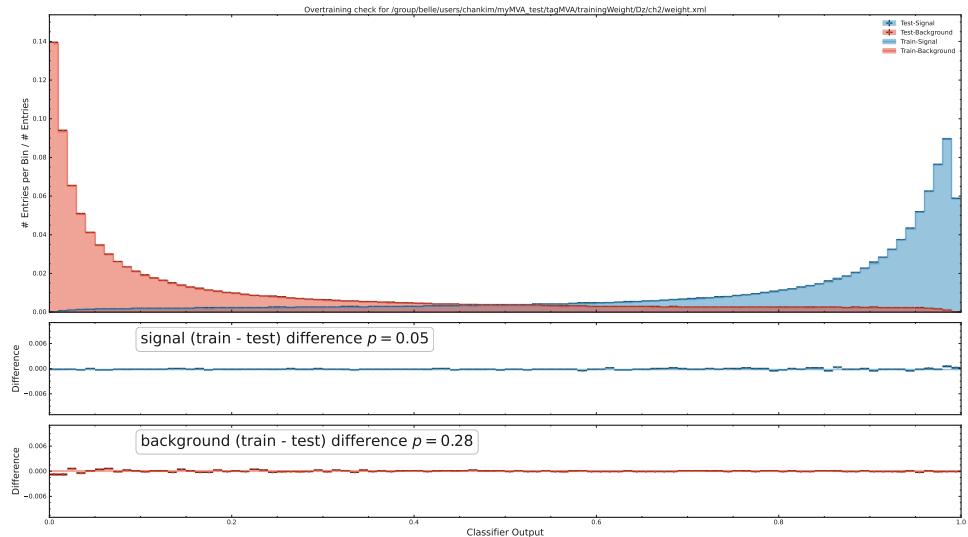


Figure 43: BDT output

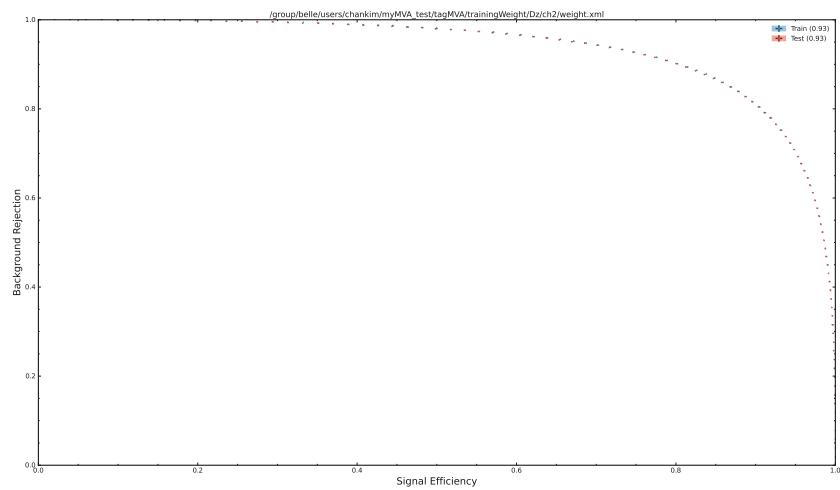


Figure 44: ROC Curve

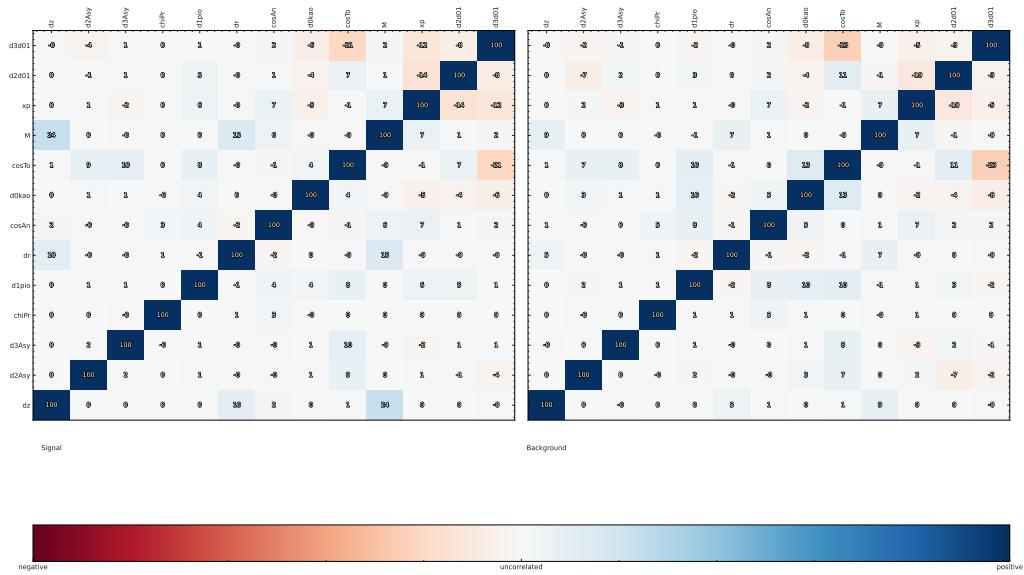


Figure 45: Correlation plot

381 A.1.4 $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$

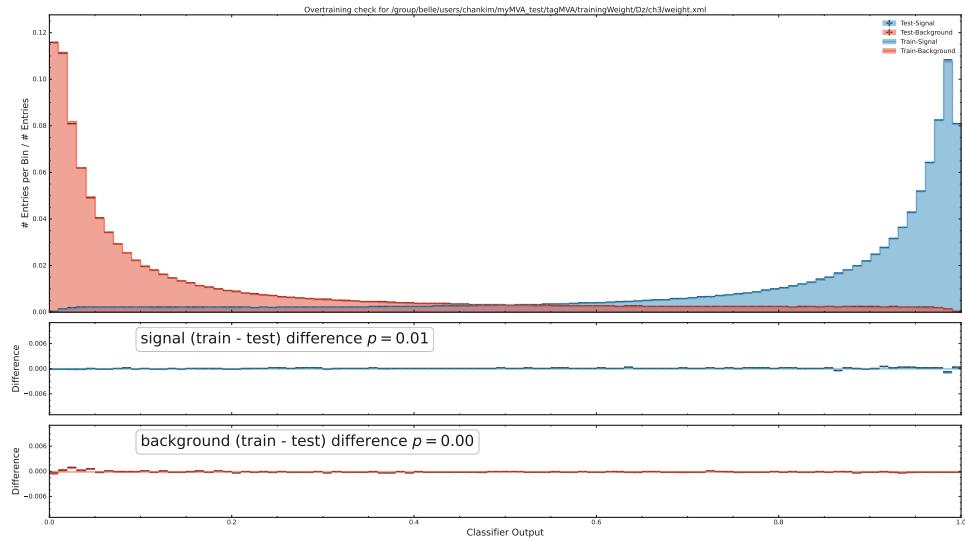


Figure 46: BDT output

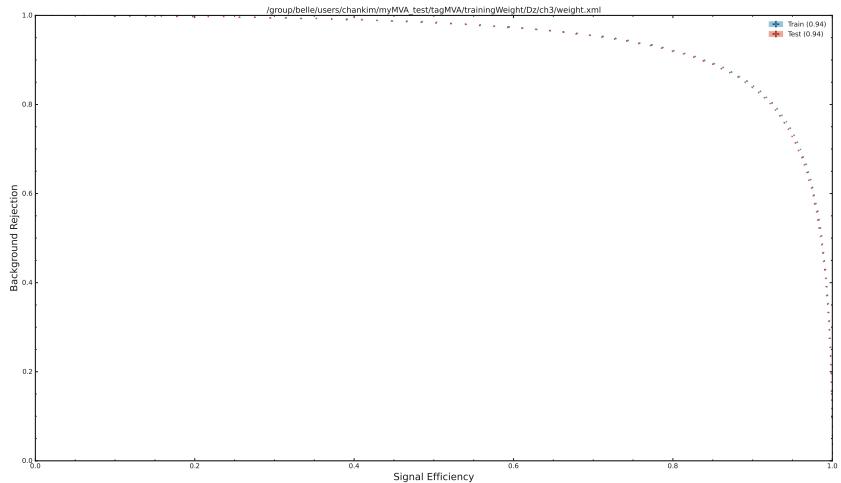


Figure 47: ROC Curve

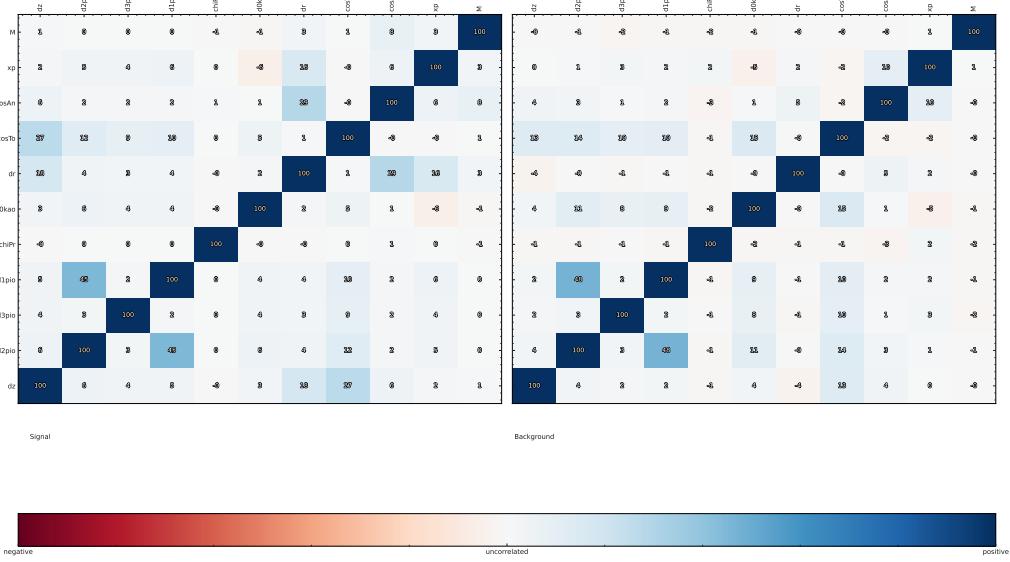


Figure 48: Correlation plot

382 A.1.5 $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+ \pi^0$

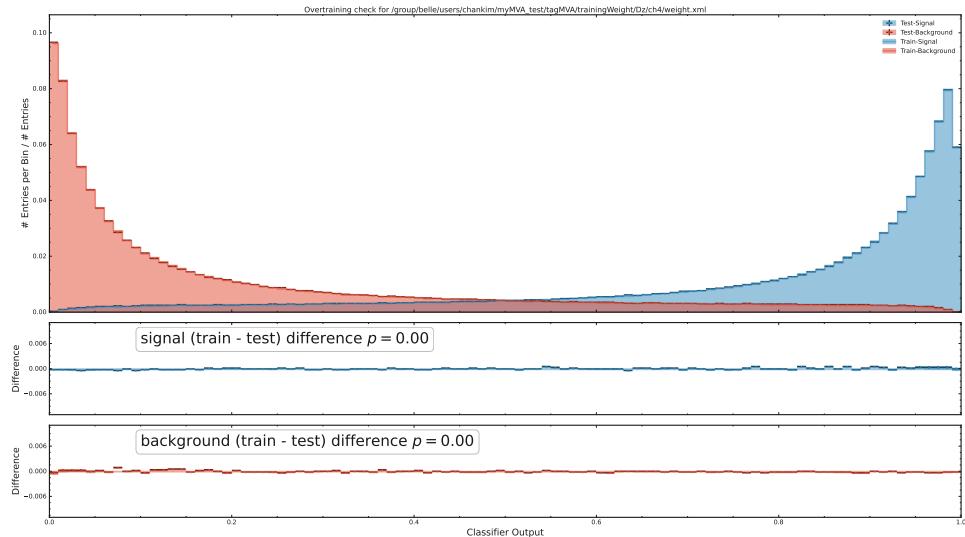


Figure 49: BDT output

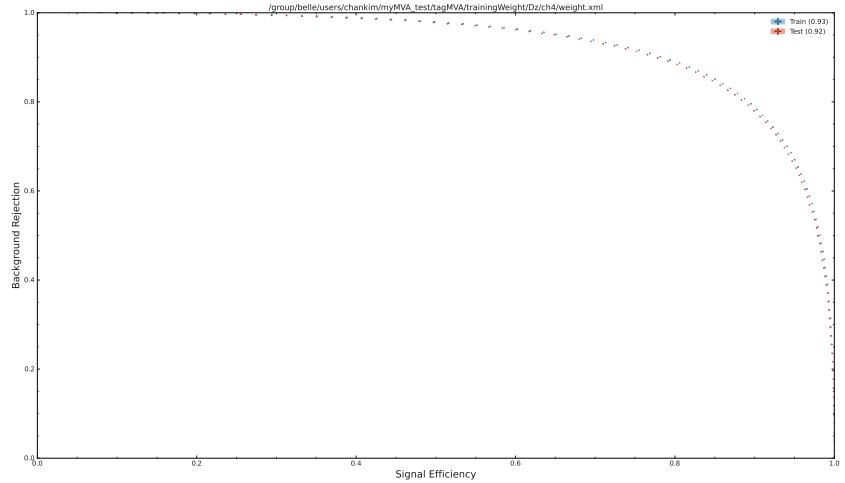


Figure 50: ROC Curve

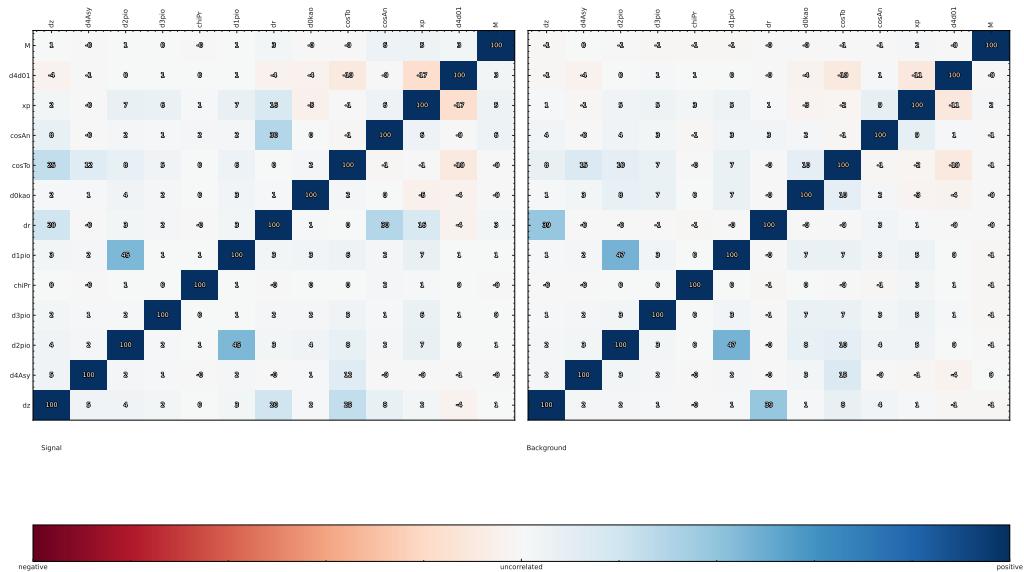


Figure 51: Correlation plot

383 A.1.6 $D^0 \rightarrow \pi^+ \pi^-$

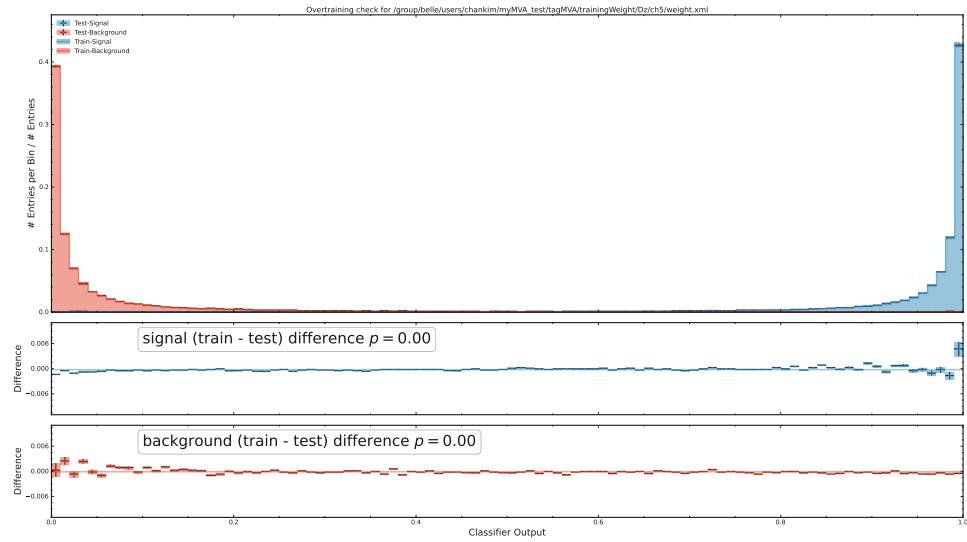


Figure 52: BDT output

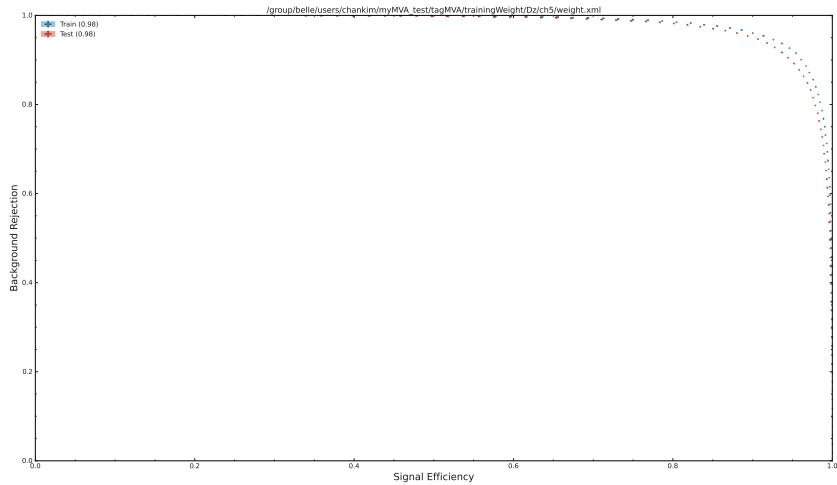


Figure 53: ROC Curve

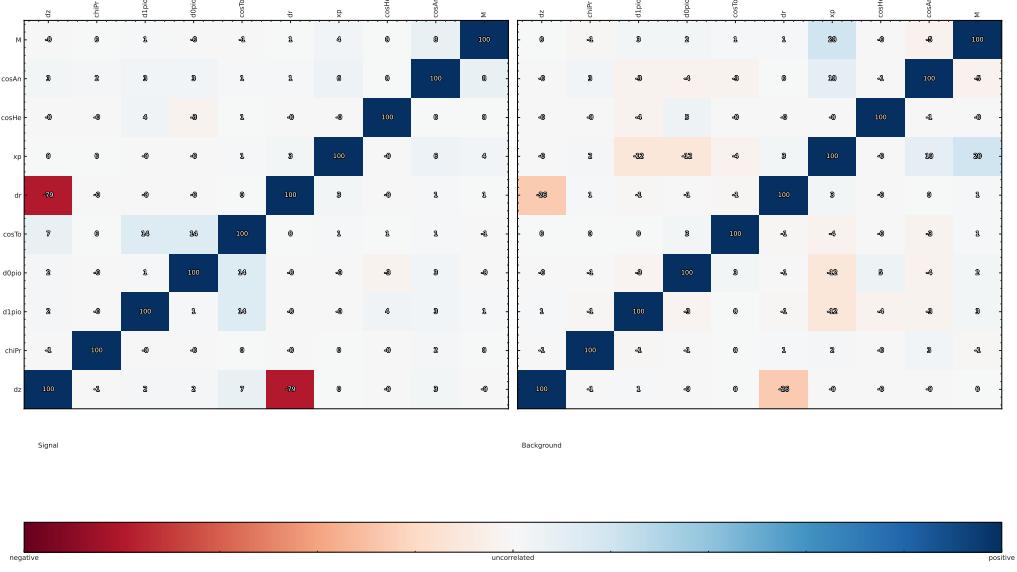


Figure 54: Correlation plot

384 A.1.7 $D^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-$

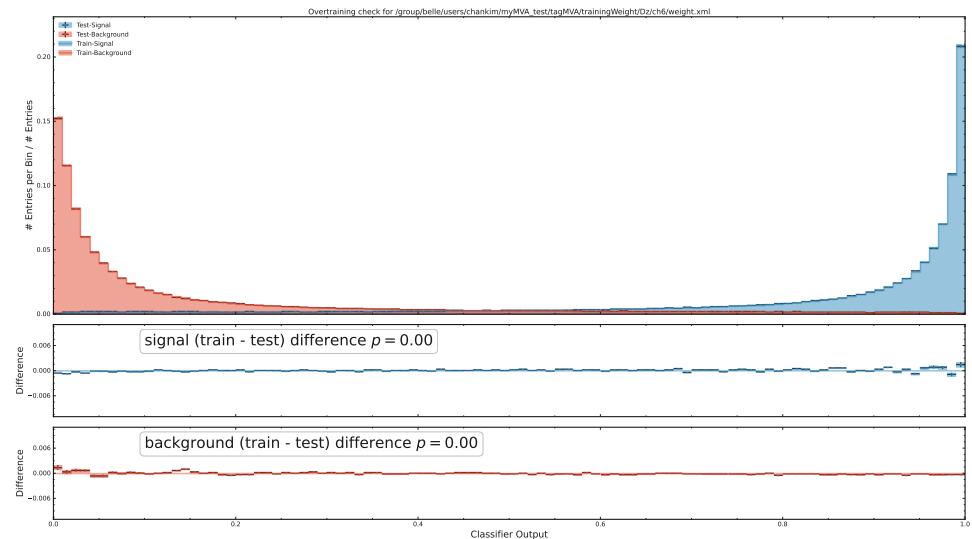


Figure 55: BDT output

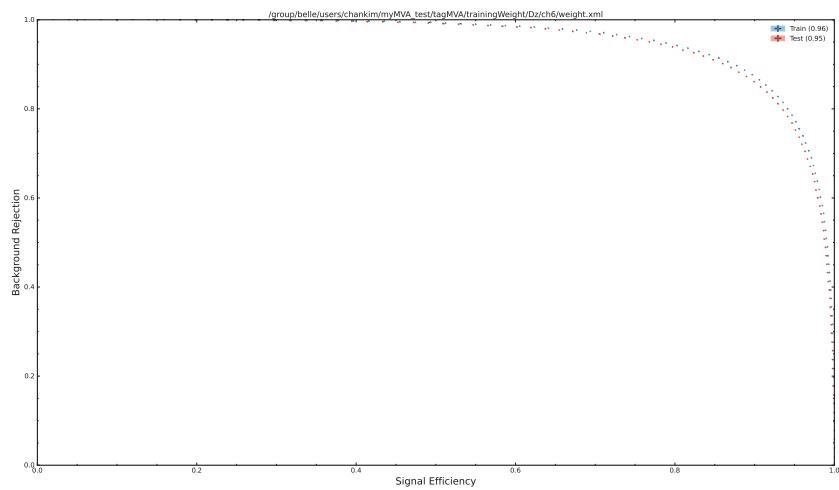


Figure 56: ROC Curve

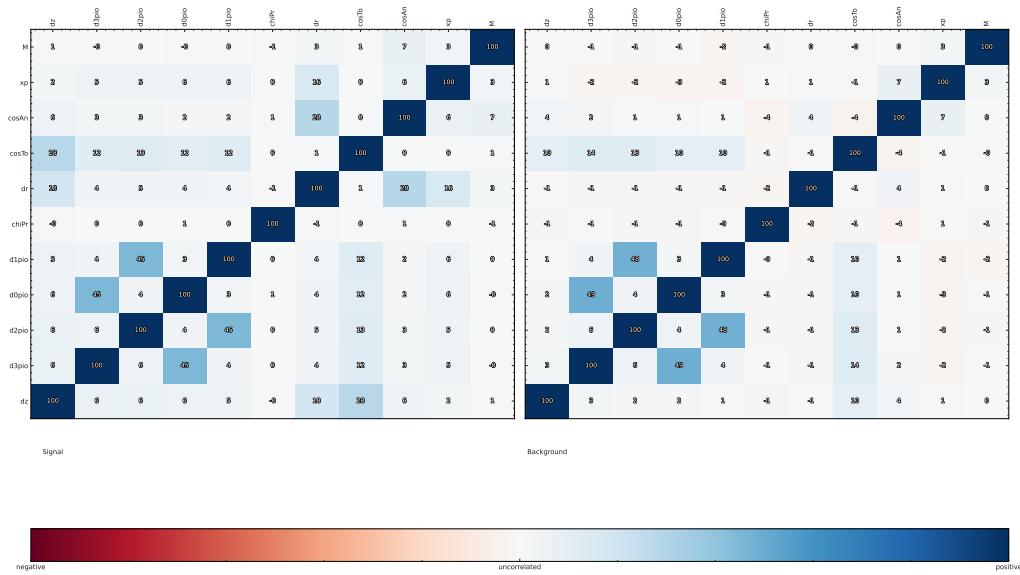


Figure 57: Correlation plot

385 A.1.8 $D^0 \rightarrow \pi^+ \pi^- \pi^0$

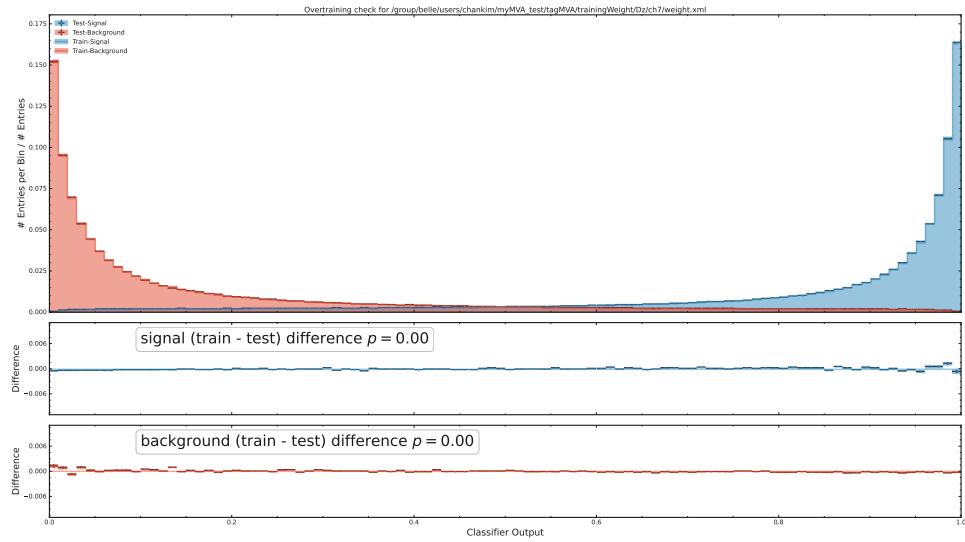


Figure 58: BDT output

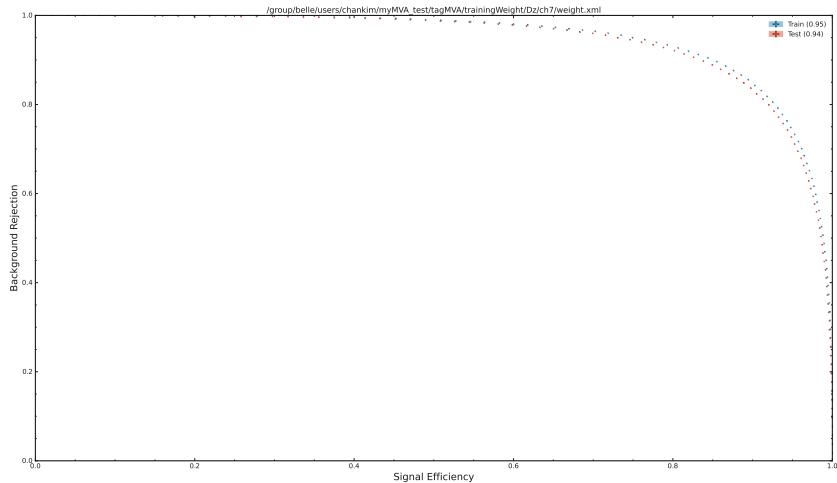


Figure 59: ROC Curve

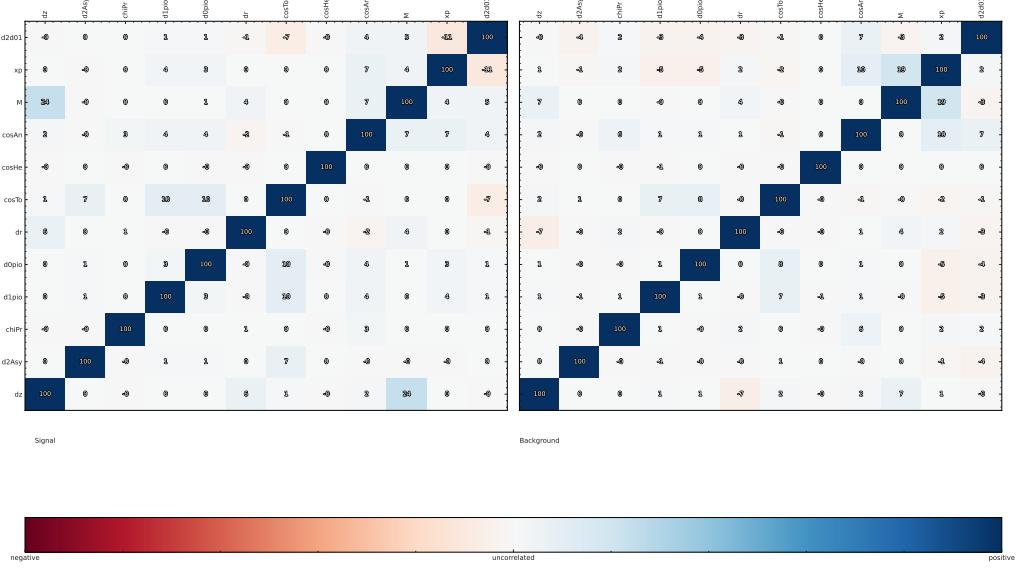


Figure 60: Correlation plot

386 A.1.9 $D^0 \rightarrow \pi^+ \pi^- \pi^0 \pi^0$

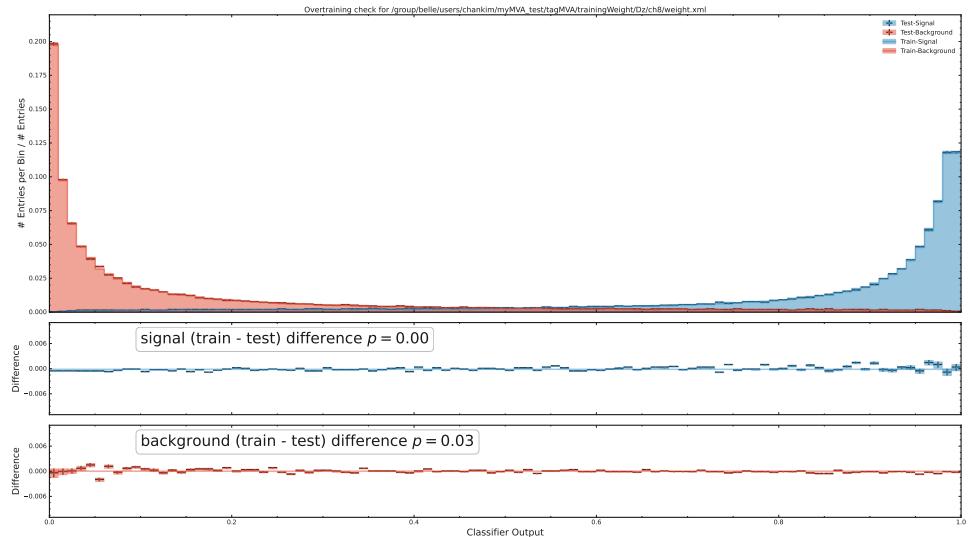


Figure 61: BDT output

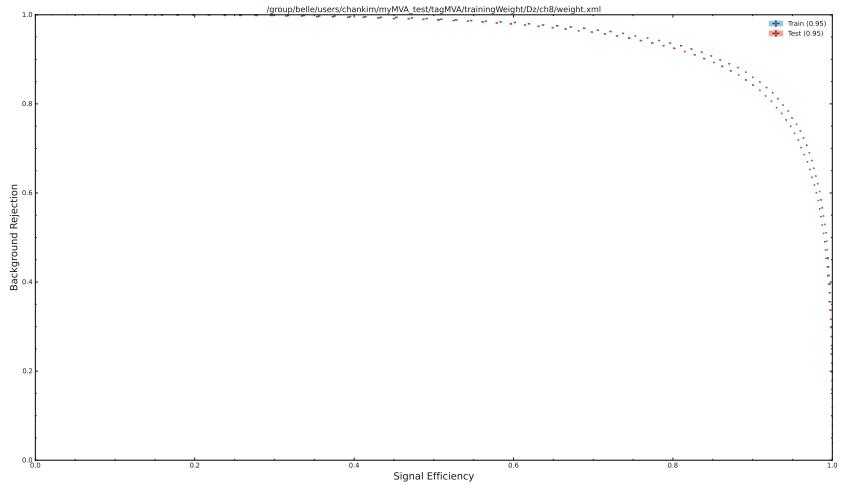


Figure 62: ROC Curve

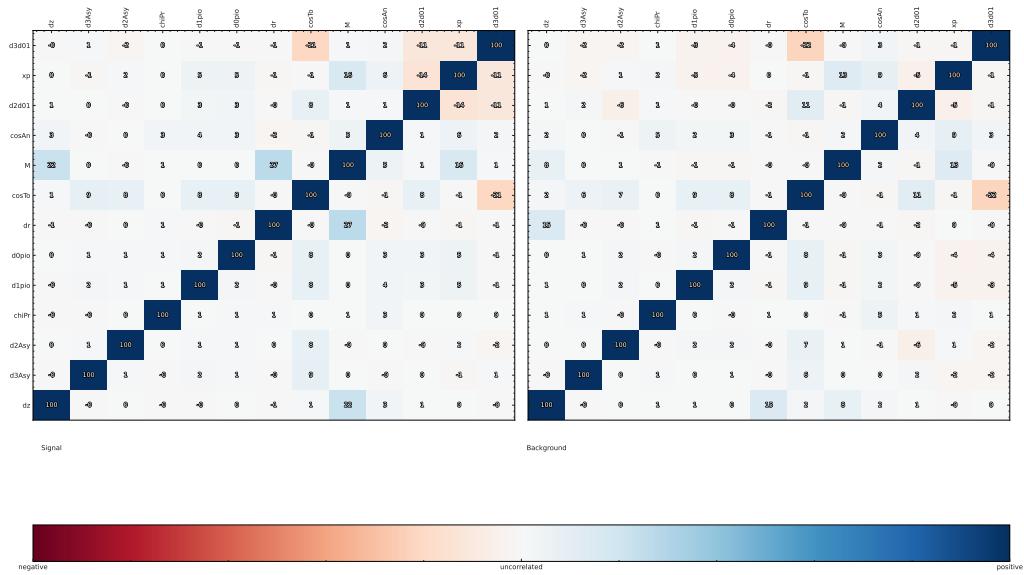


Figure 63: Correlation plot

387 **A.1.10** $D^0 \rightarrow \pi^+ \pi^- K_S^0$

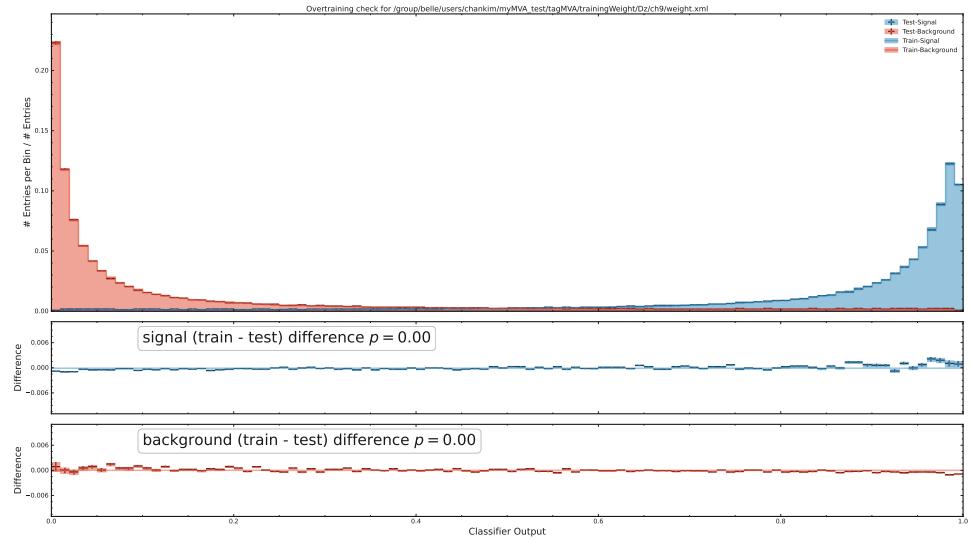


Figure 64: BDT output

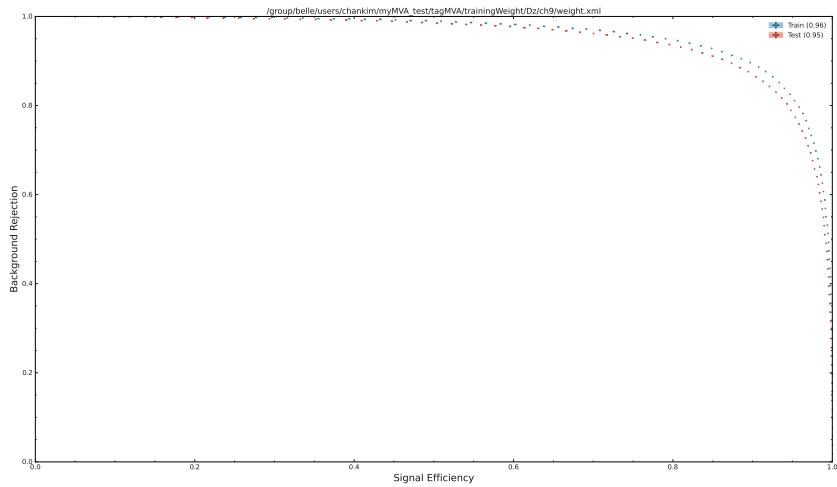


Figure 65: ROC Curve

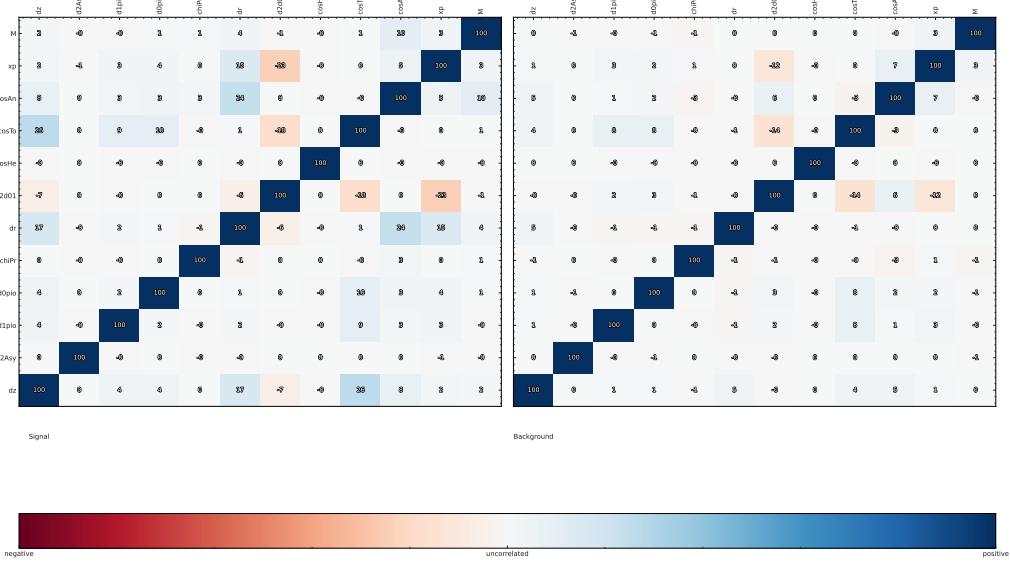


Figure 66: Correlation plot

388 A.1.11 $D^0 \rightarrow \pi^+\pi^-\pi^0 K_S^0$

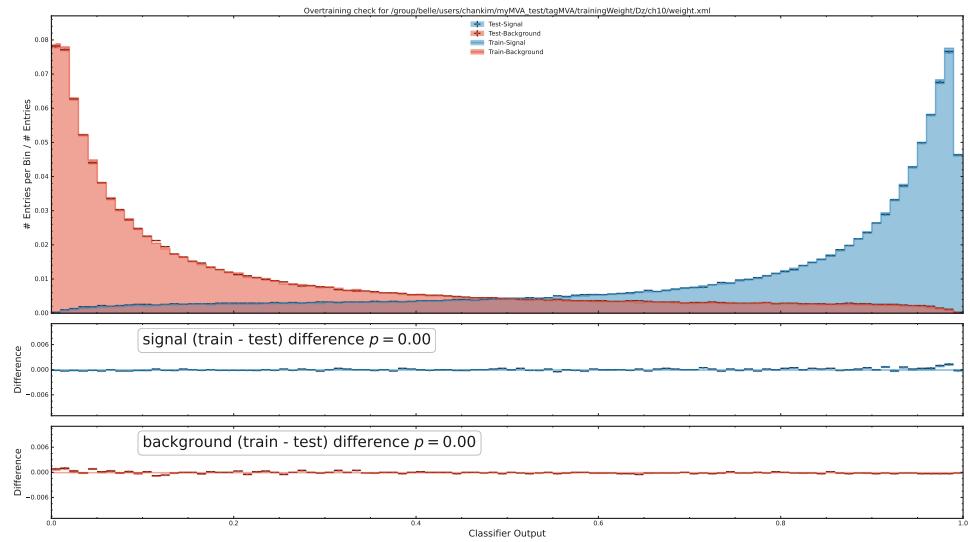


Figure 67: BDT output

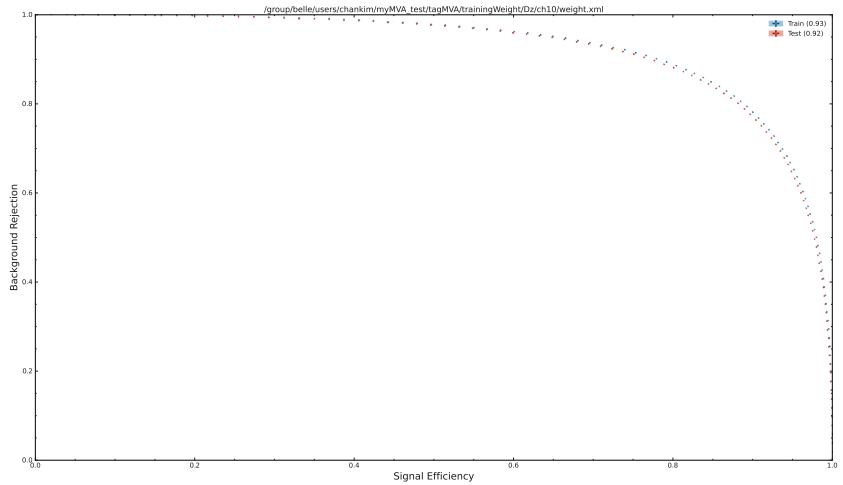
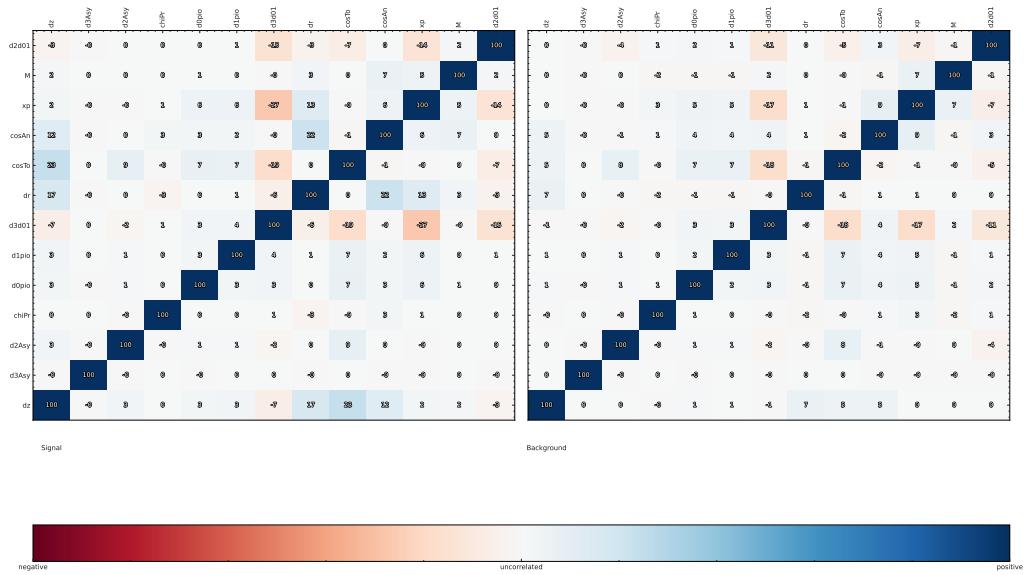


Figure 68: ROC Curve



389 **A.1.12** $D^0 \rightarrow \pi^0 K_S^0$

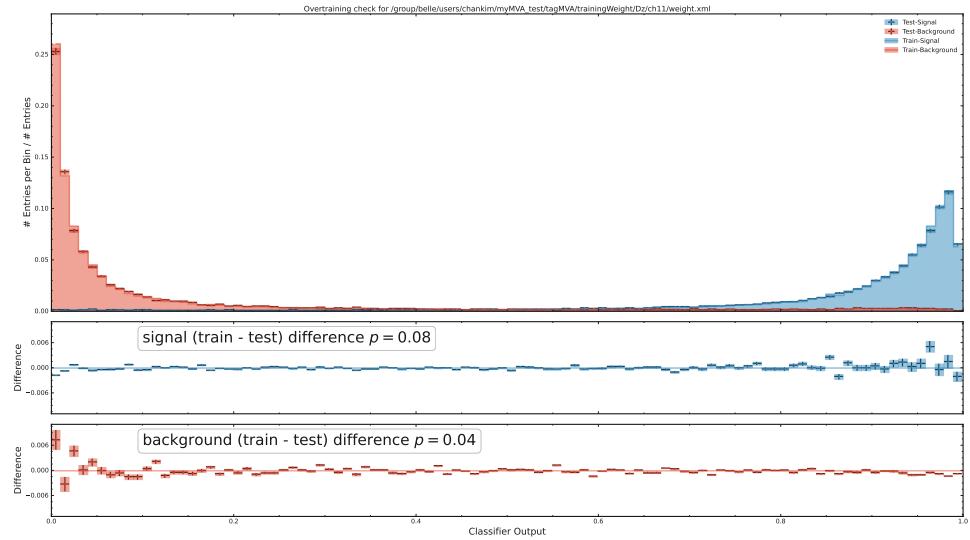


Figure 70: BDT output

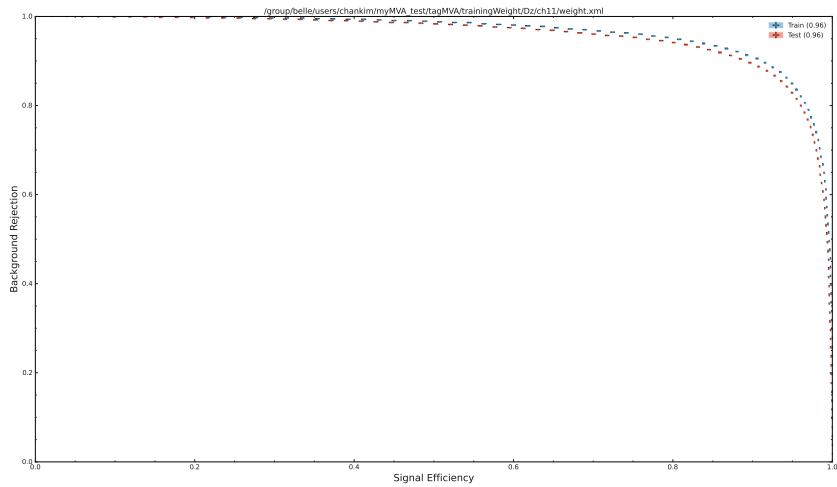


Figure 71: ROC Curve

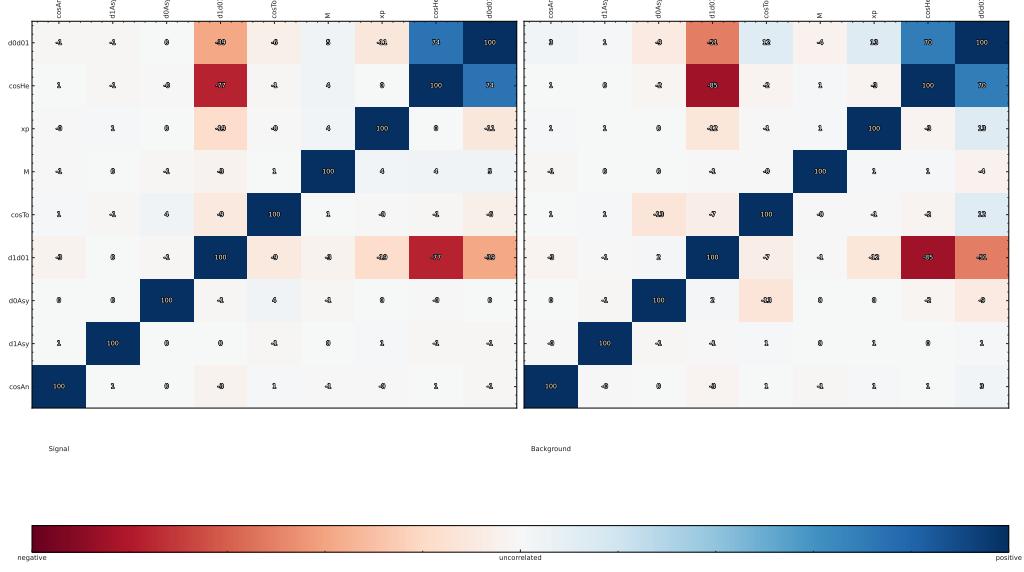


Figure 72: Correlation plot

390 A.1.13 $D^0 \rightarrow K^+K^-$

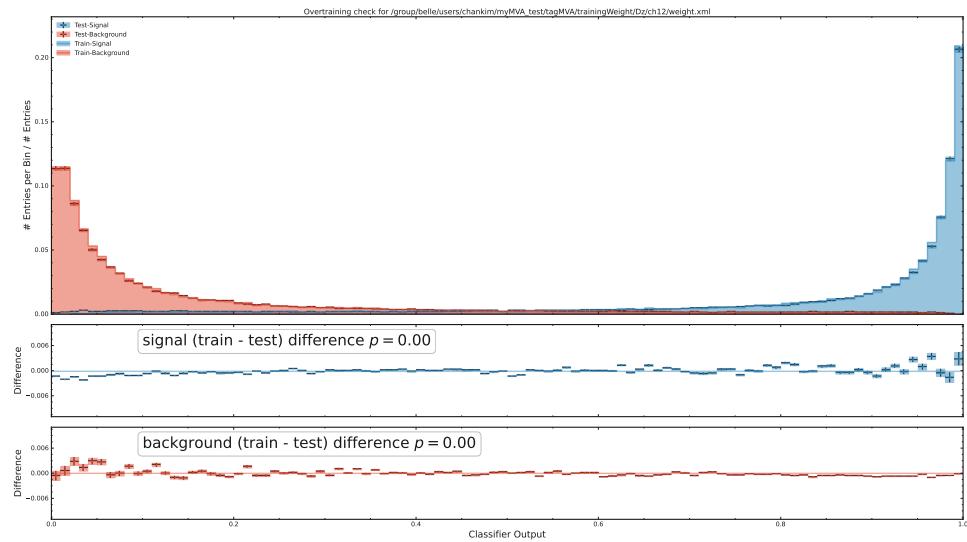


Figure 73: BDT output

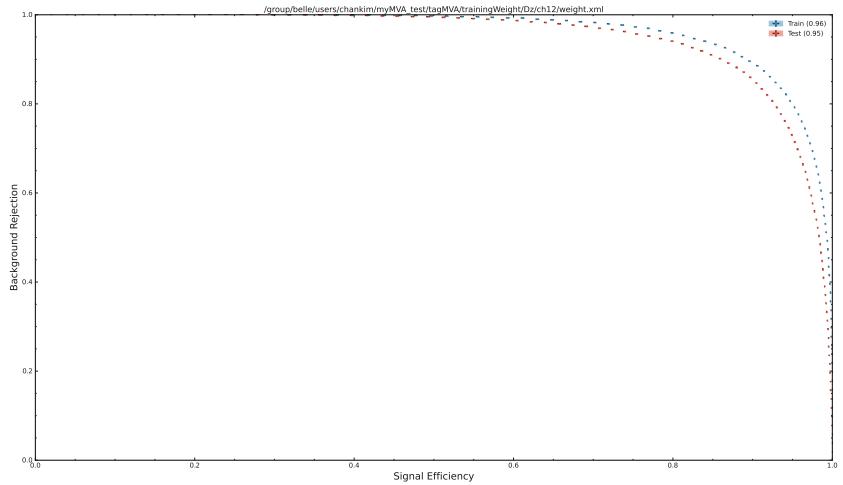


Figure 74: ROC Curve

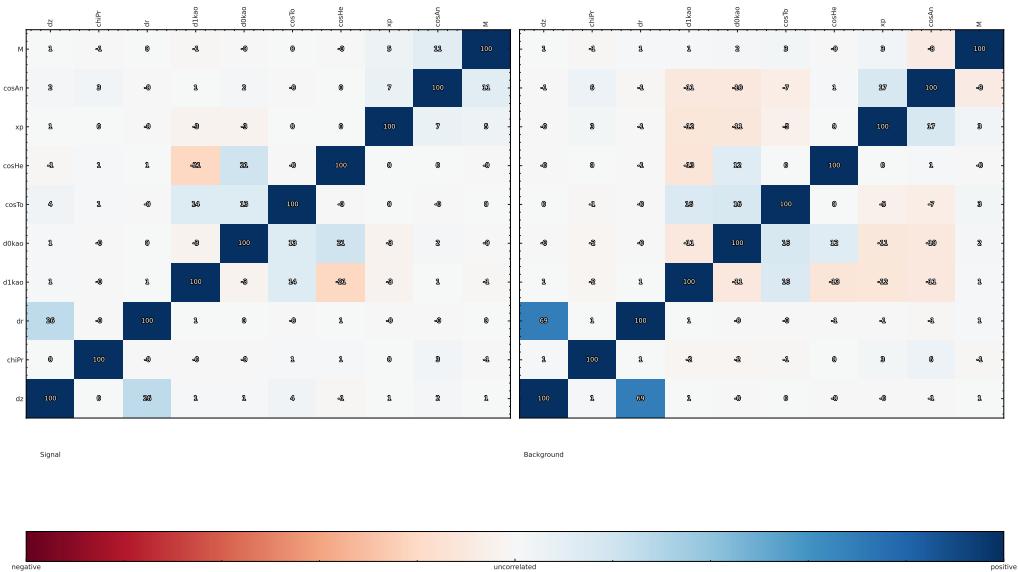


Figure 75: Correlation plot

391 A.1.14 $D^0 \rightarrow K^+K^-\pi^0$

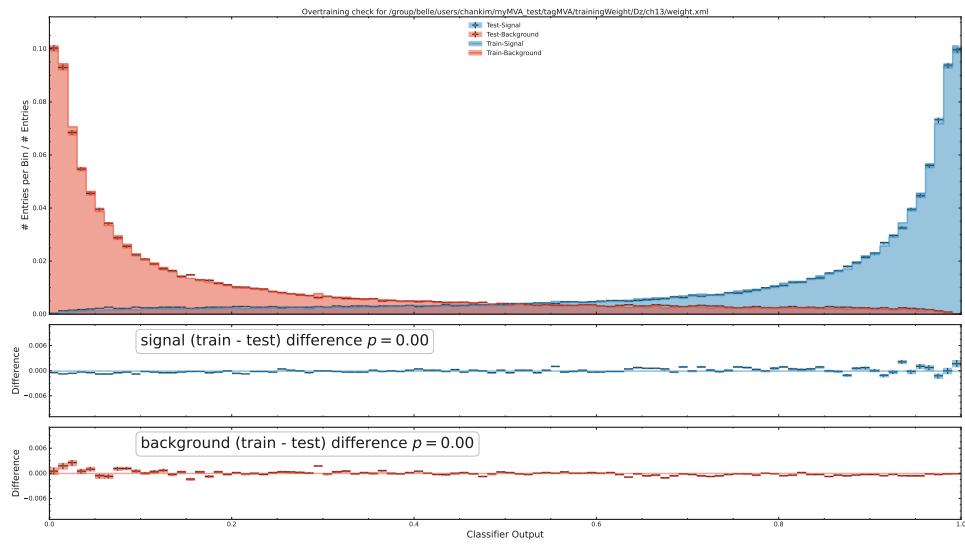


Figure 76: BDT output

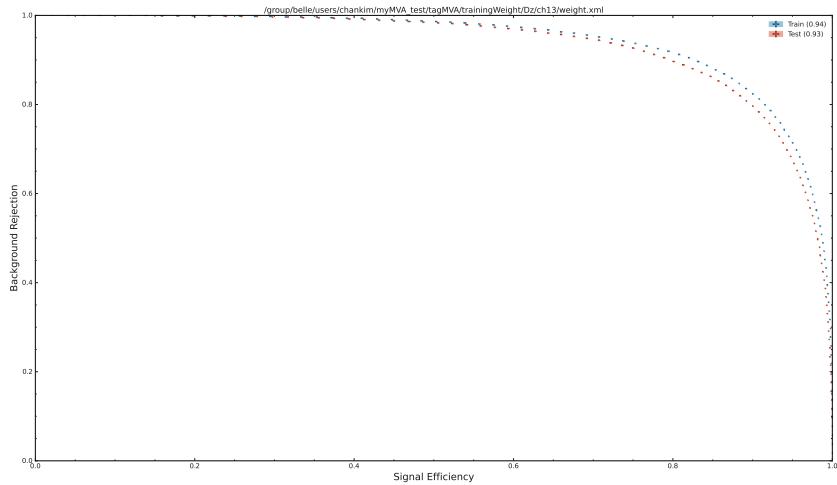


Figure 77: ROC Curve

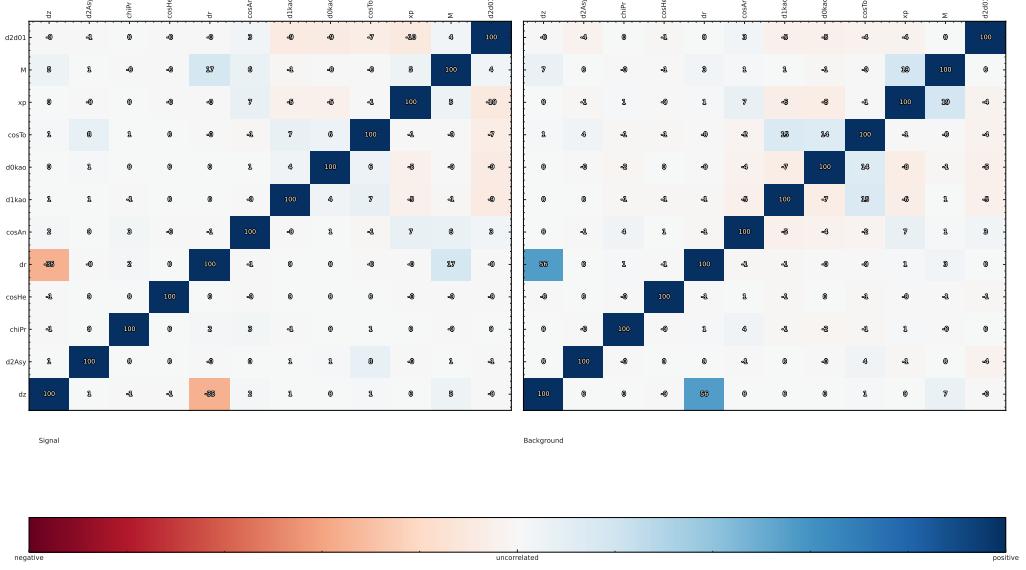


Figure 78: Correlation plot

392 A.1.15 $D^0 \rightarrow K^+ K^- K_S^0$

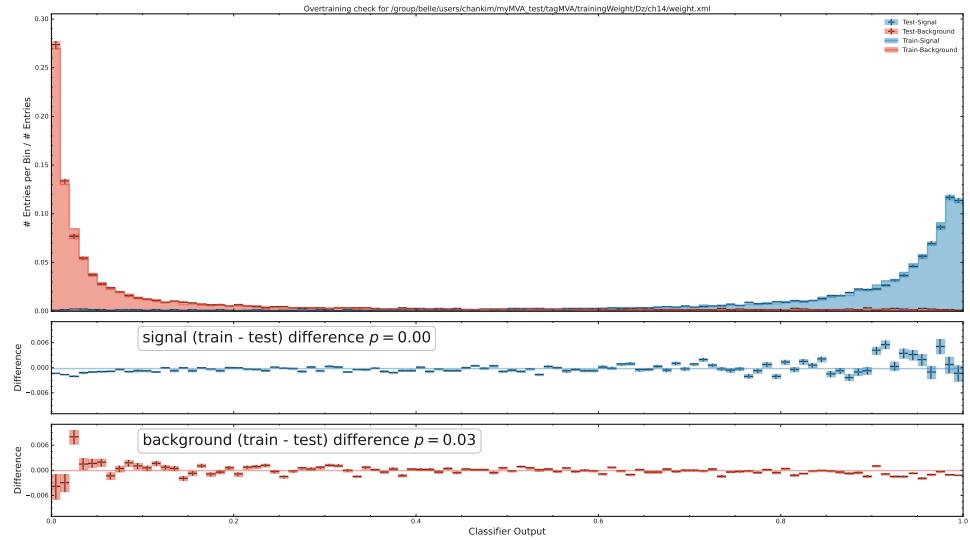


Figure 79: BDT output

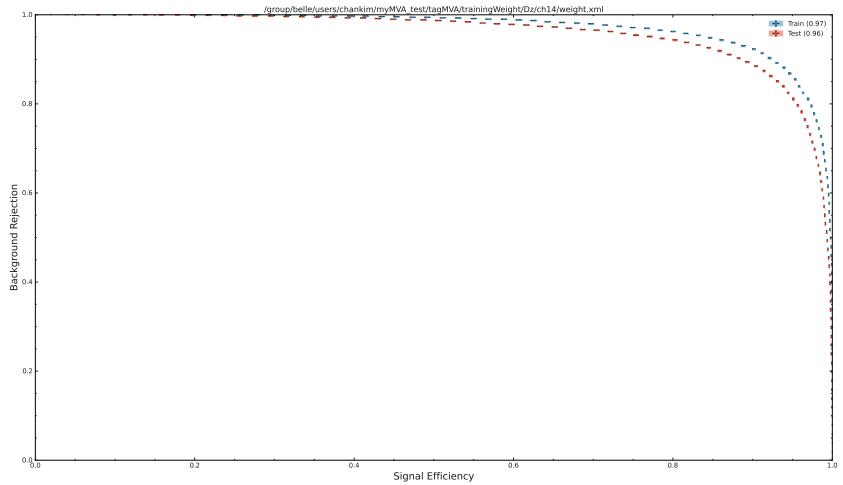


Figure 80: ROC Curve

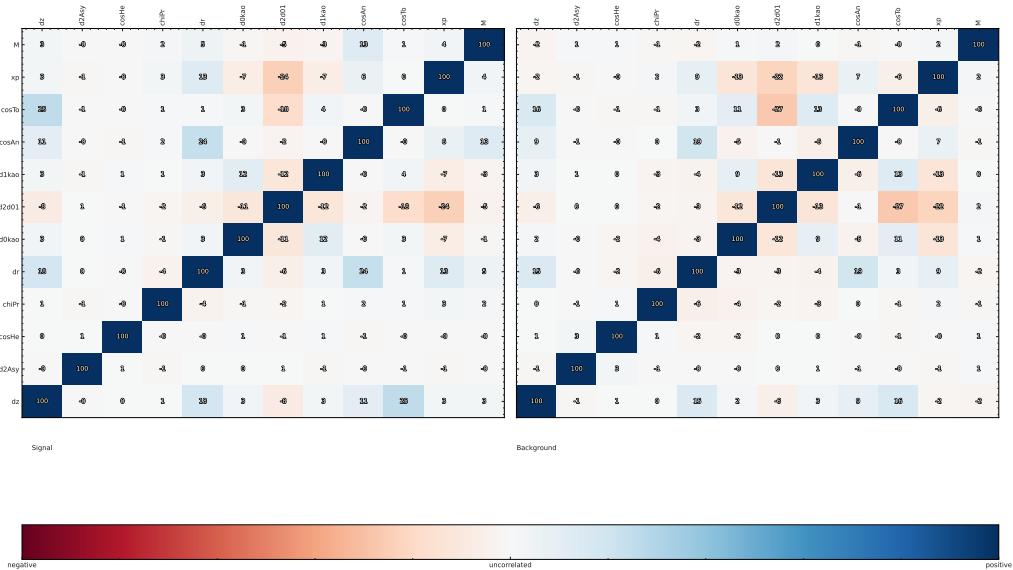


Figure 81: Correlation plot

393 A.1.16 $D^+ \rightarrow K^-\pi^+\pi^+$

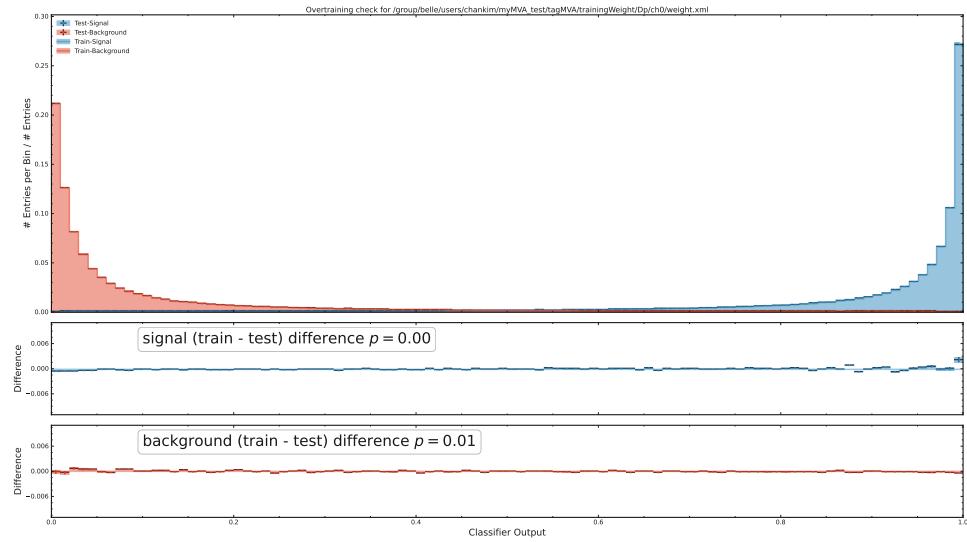


Figure 82: BDT output

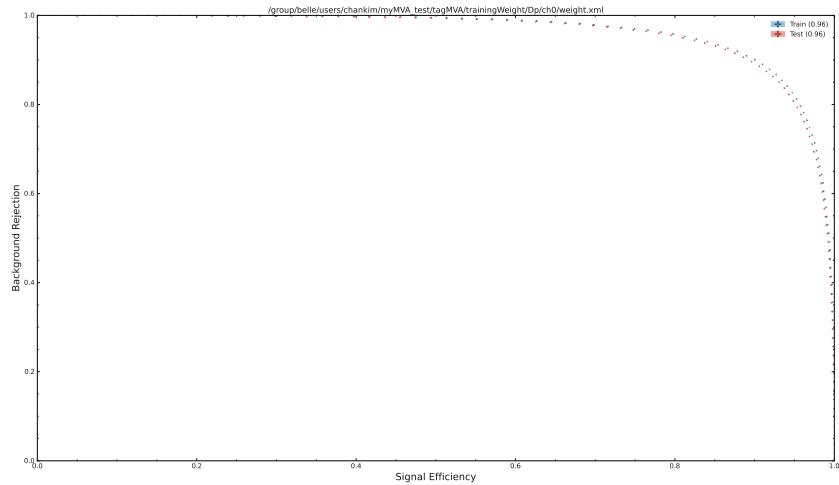


Figure 83: ROC Curve

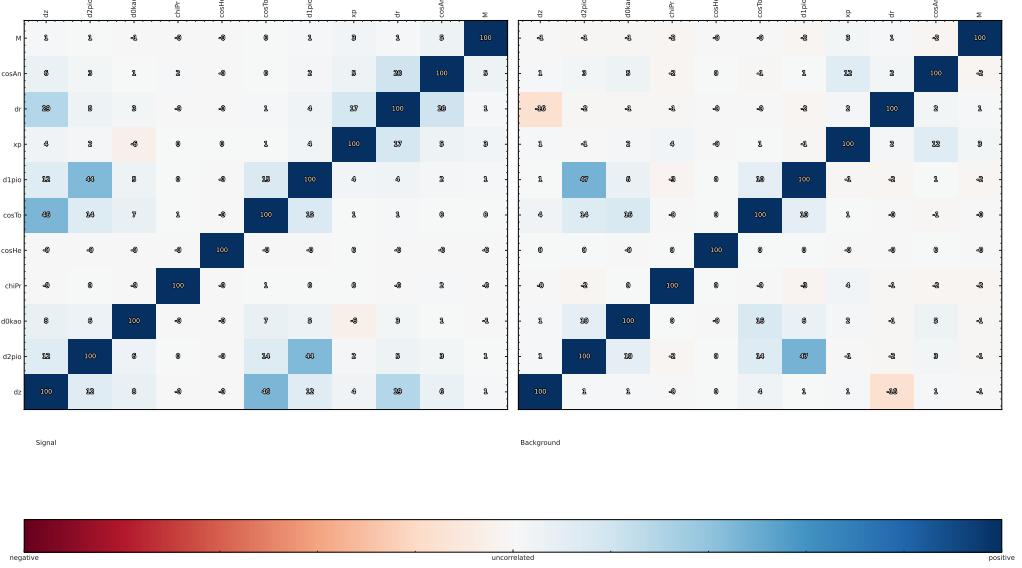


Figure 84: Correlation plot

394 A.1.17 $D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$

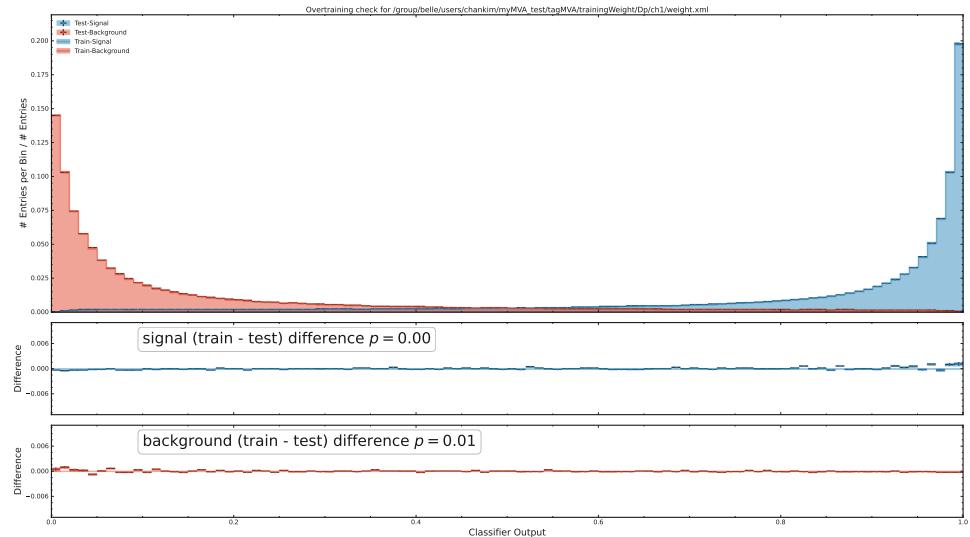


Figure 85: BDT output

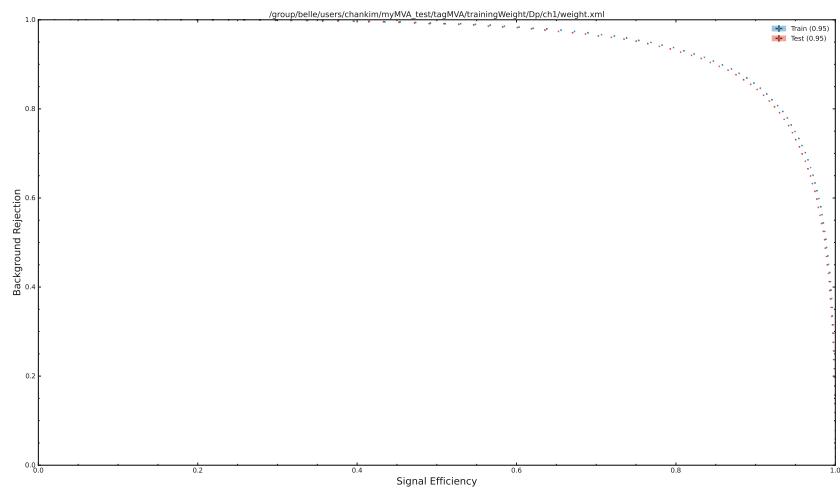


Figure 86: ROC Curve

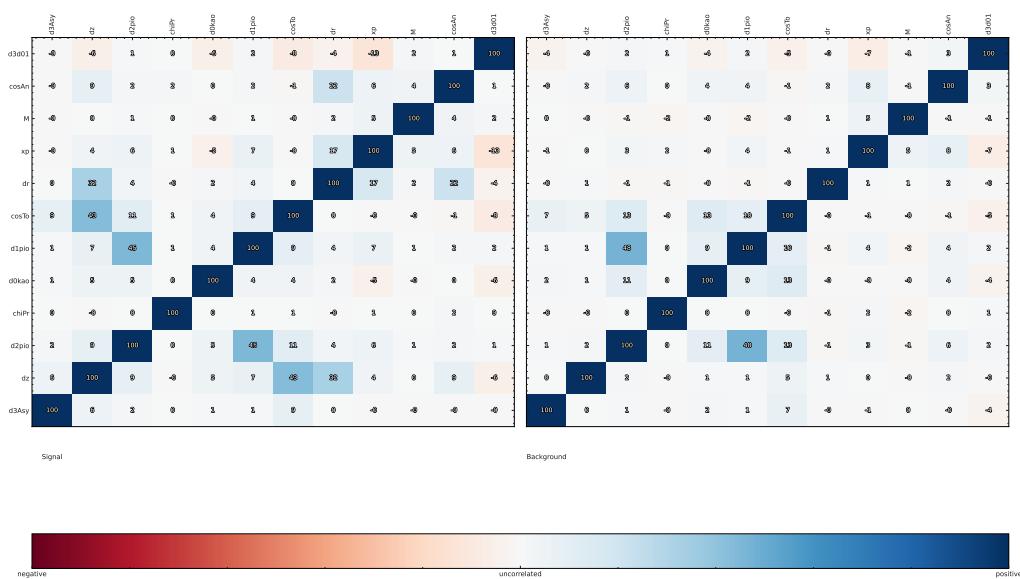


Figure 87: Correlation plot

395 A.1.18 $D^+ \rightarrow K^- K^+ \pi^+$

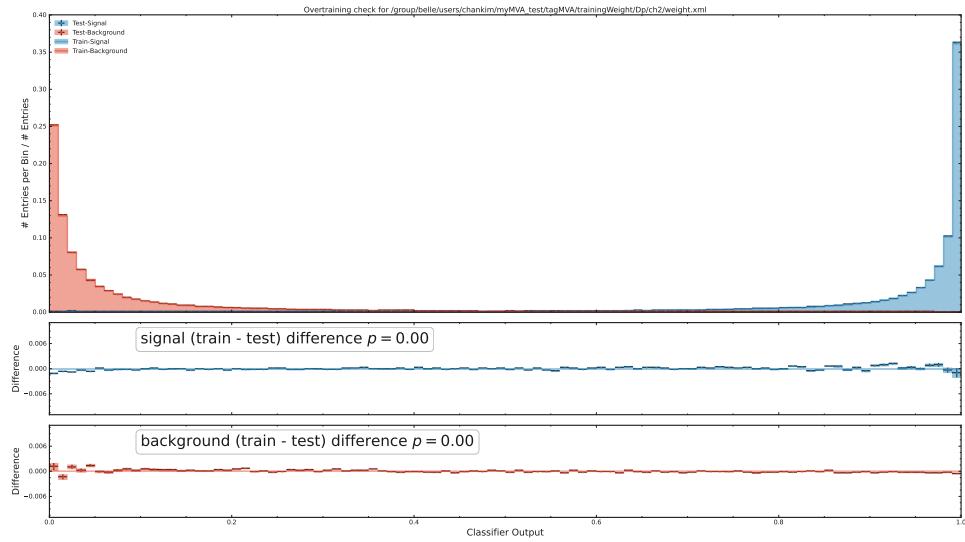


Figure 88: BDT output

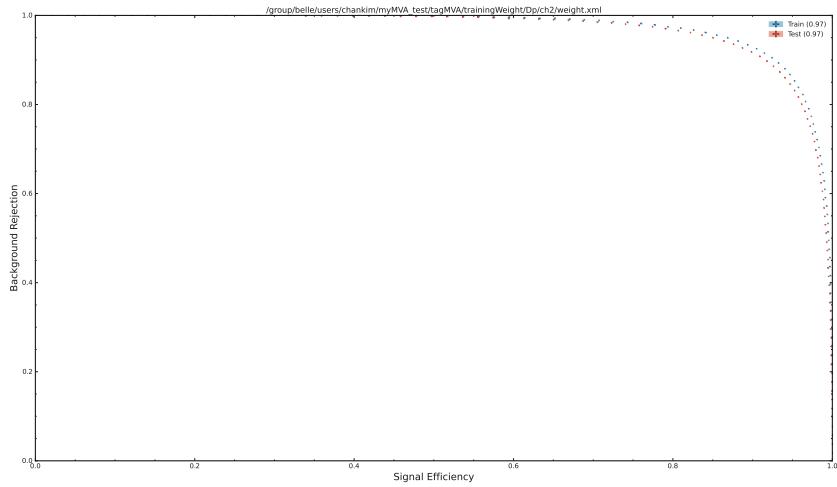


Figure 89: ROC Curve

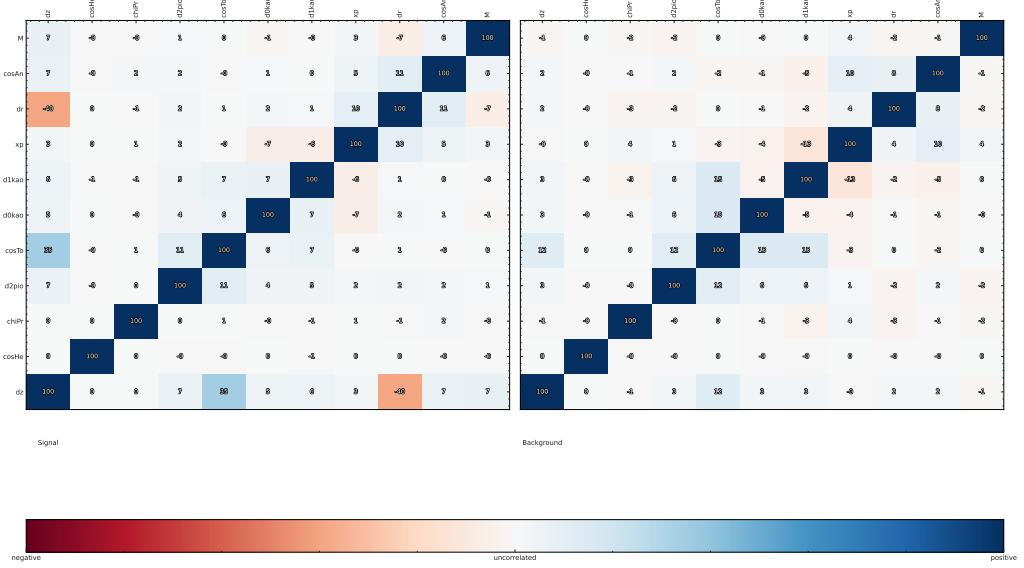


Figure 90: Correlation plot

396 A.1.19 $D^+ \rightarrow K^- K^+ \pi^+ \pi^0$

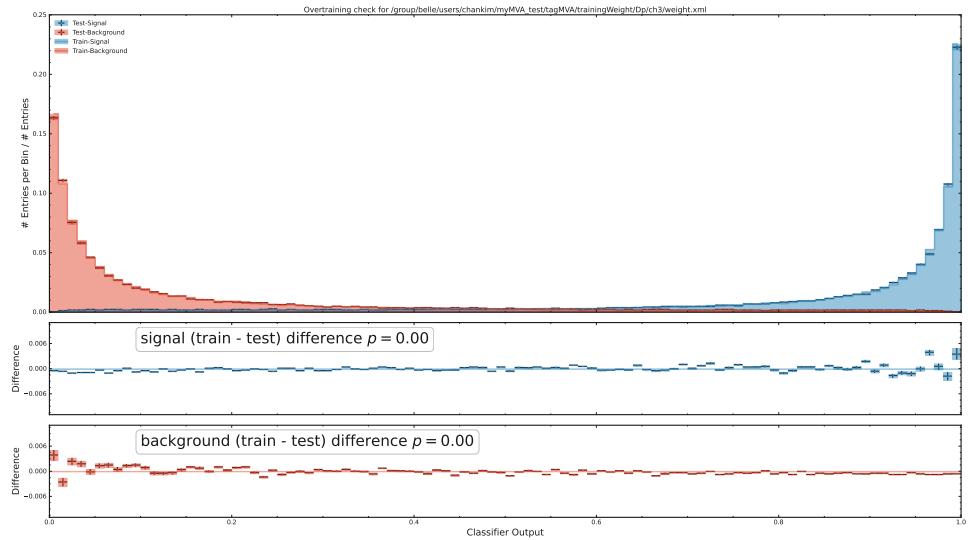


Figure 91: BDT output

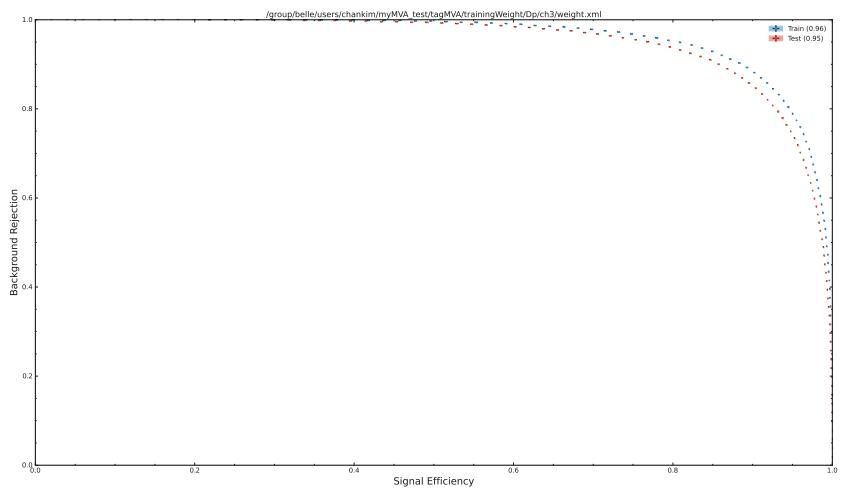


Figure 92: ROC Curve

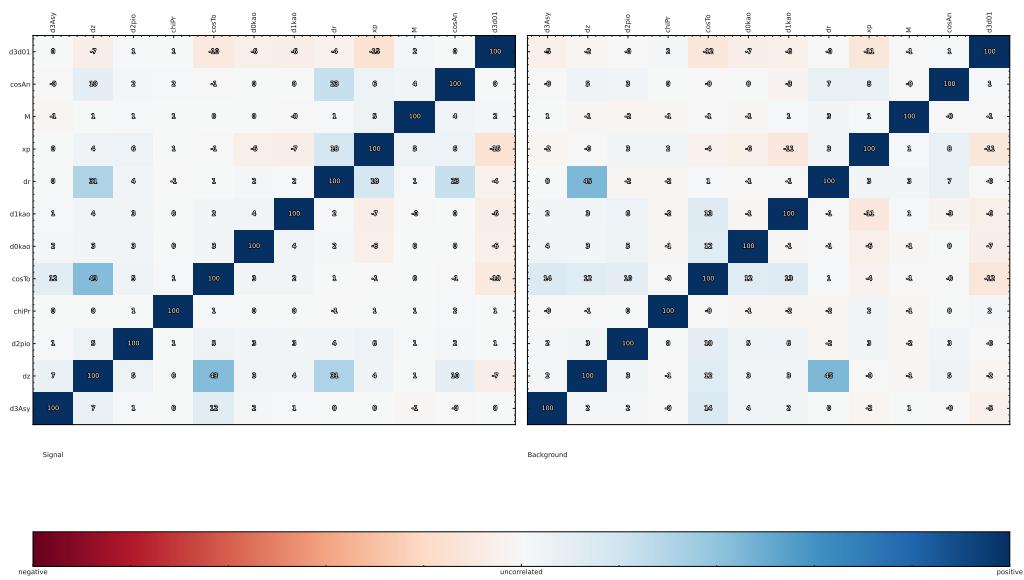


Figure 93: Correlation plot

397 A.1.20 $D^+ \rightarrow \pi^+ \pi^0$

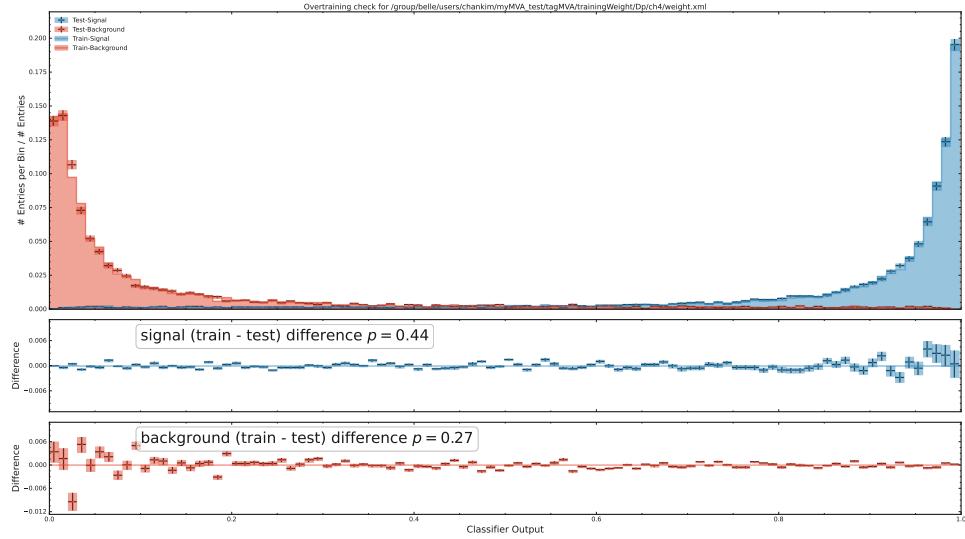


Figure 94: BDT output

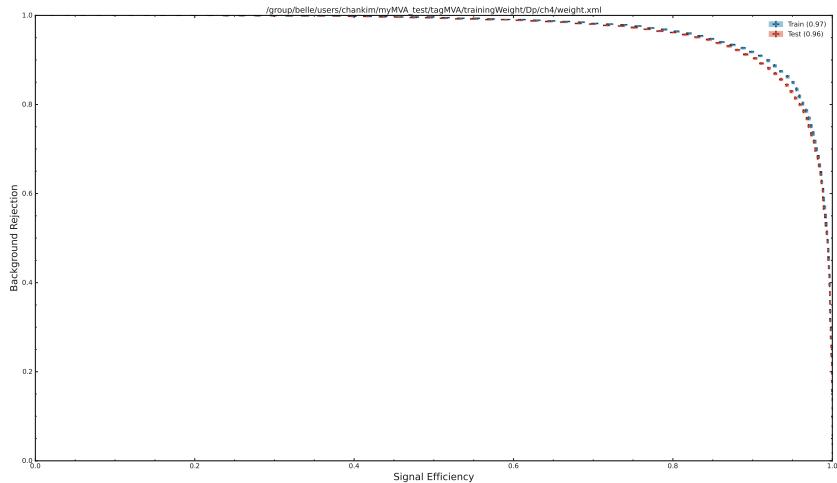


Figure 95: ROC Curve

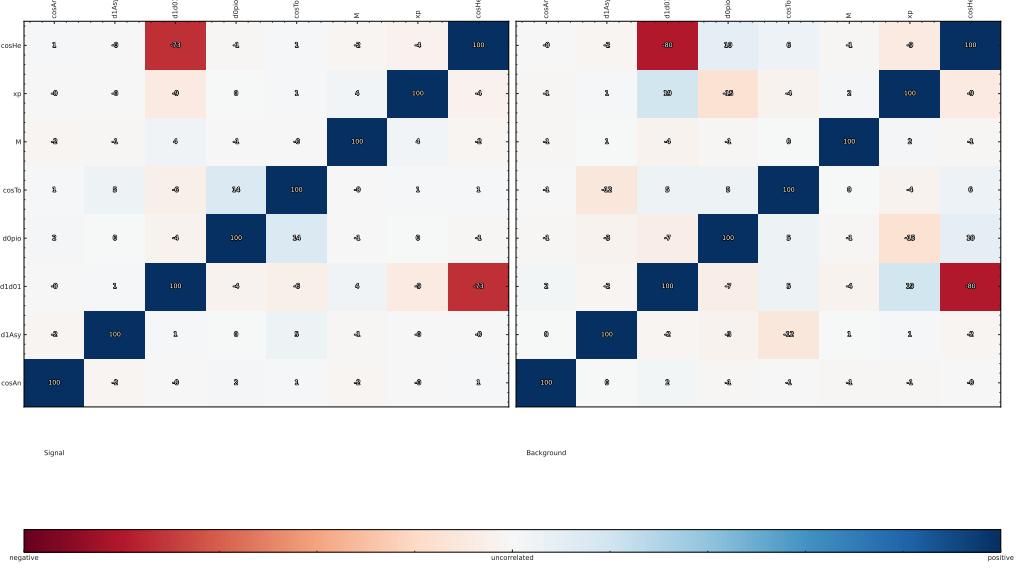


Figure 96: Correlation plot

398 A.1.21 $D^+ \rightarrow \pi^+\pi^-\pi^+$

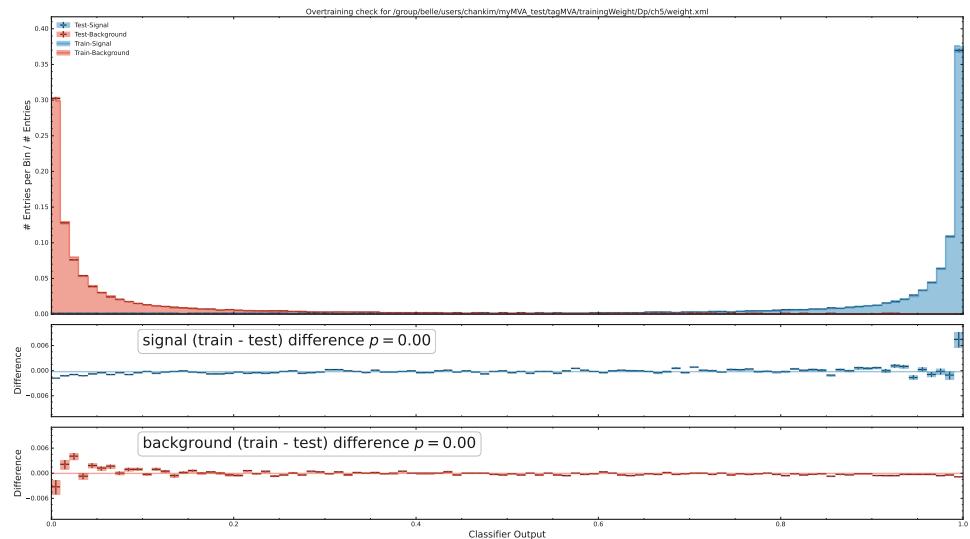


Figure 97: BDT output

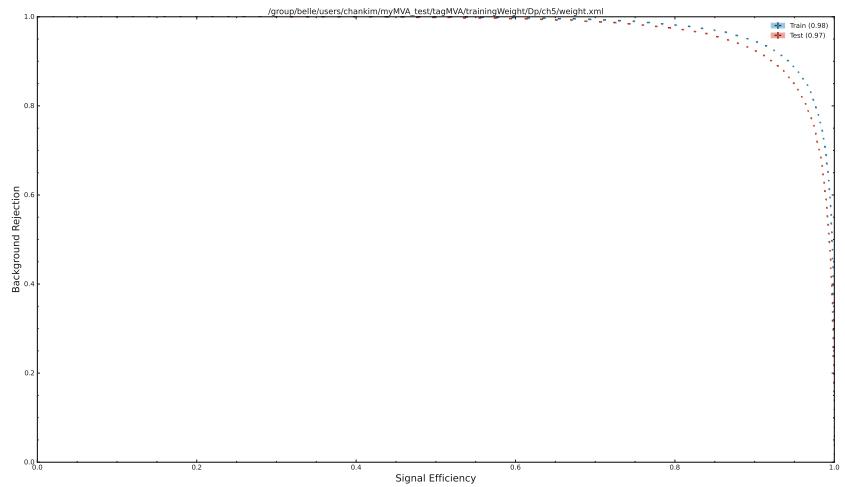


Figure 98: ROC Curve

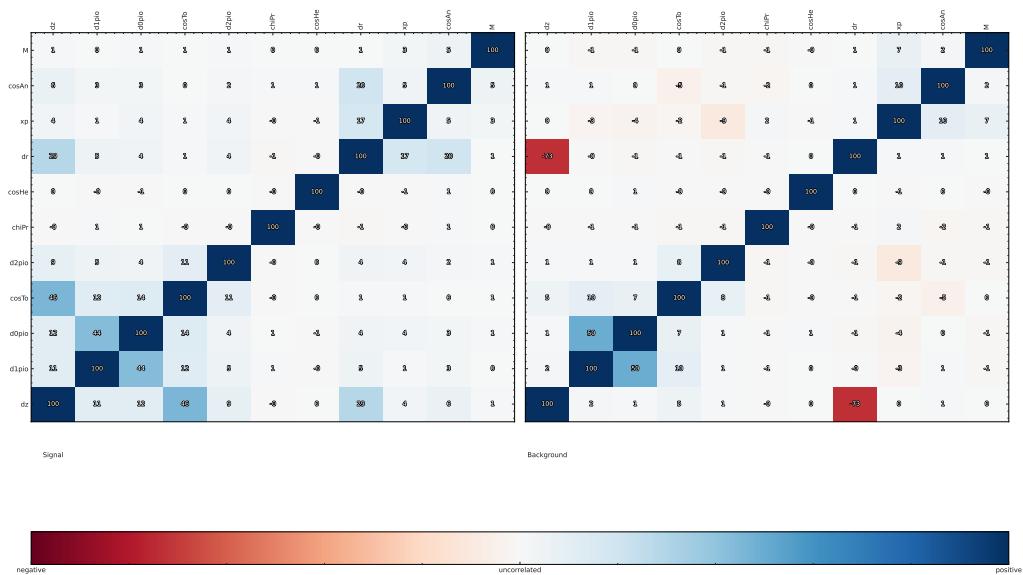


Figure 99: Correlation plot

399 A.1.22 $D^+ \rightarrow \pi^+ \pi^- \pi^+ \pi^0$

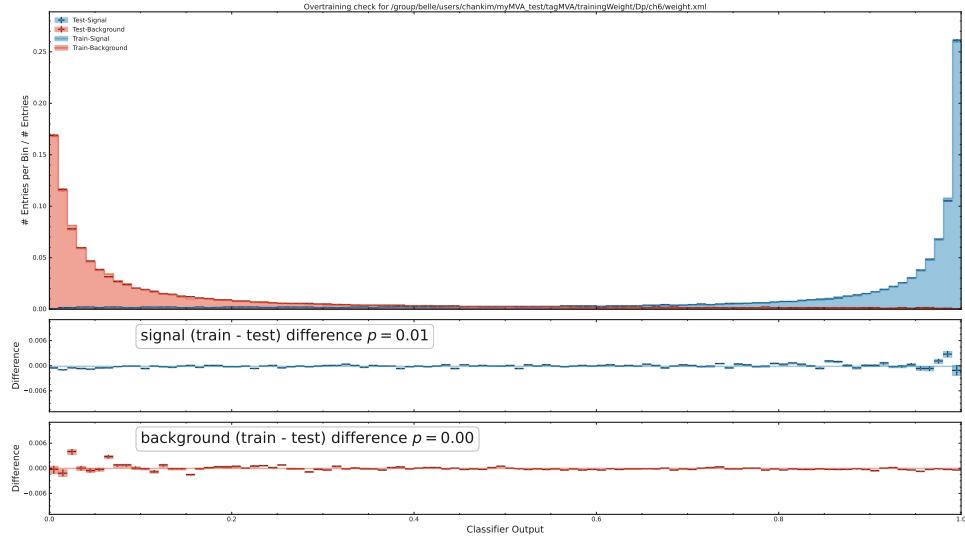


Figure 100: BDT output

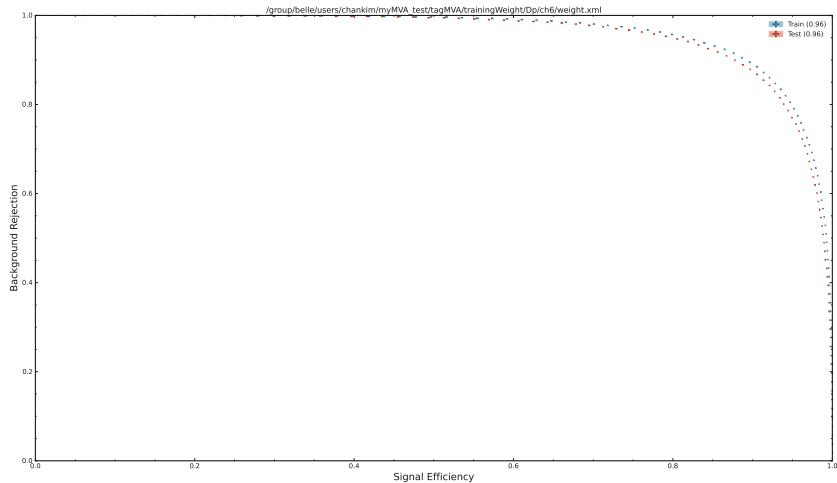


Figure 101: ROC Curve

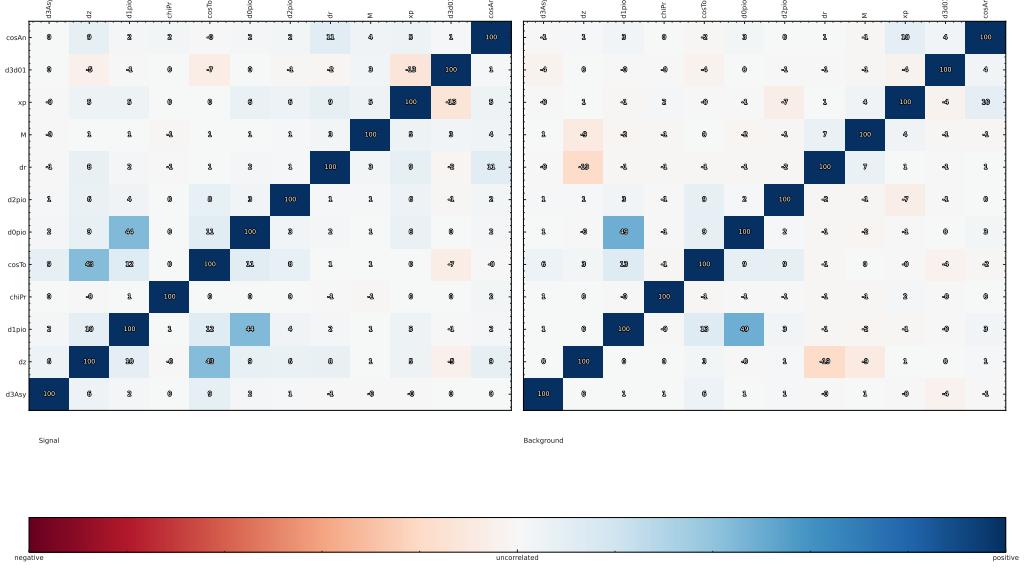


Figure 102: Correlation plot

400 A.1.23 $D^+ \rightarrow \pi^+ K_S^0$

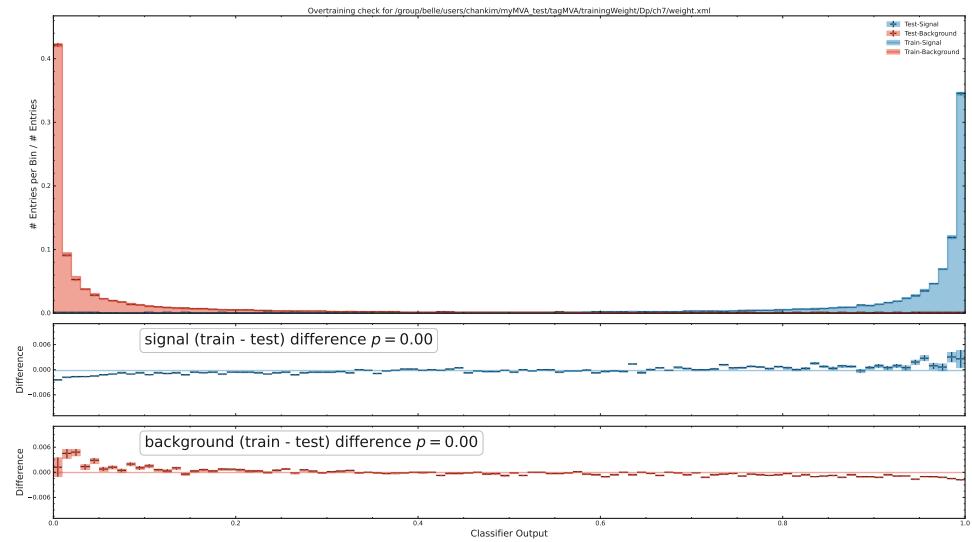


Figure 103: BDT output

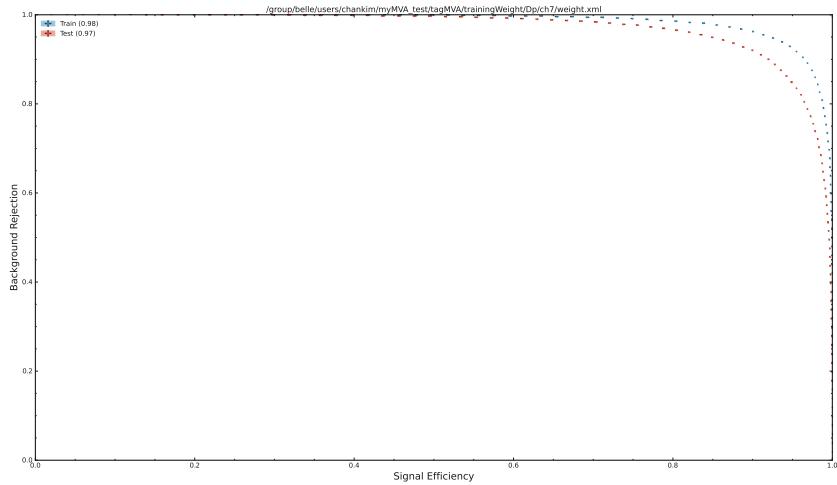


Figure 104: ROC Curve

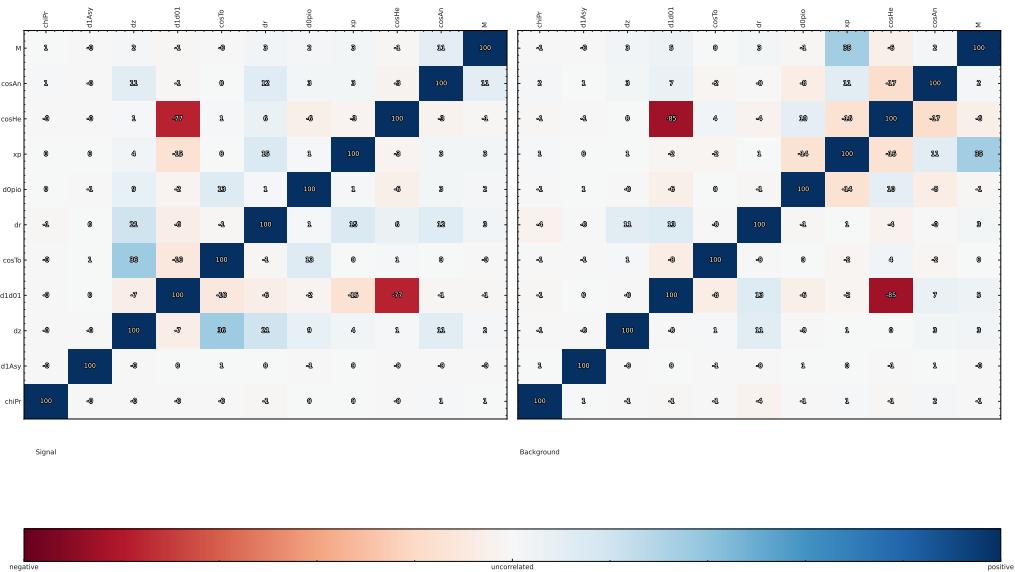


Figure 105: Correlation plot

401 A.1.24 $D^+ \rightarrow \pi^+ \pi^0 K_S^0$

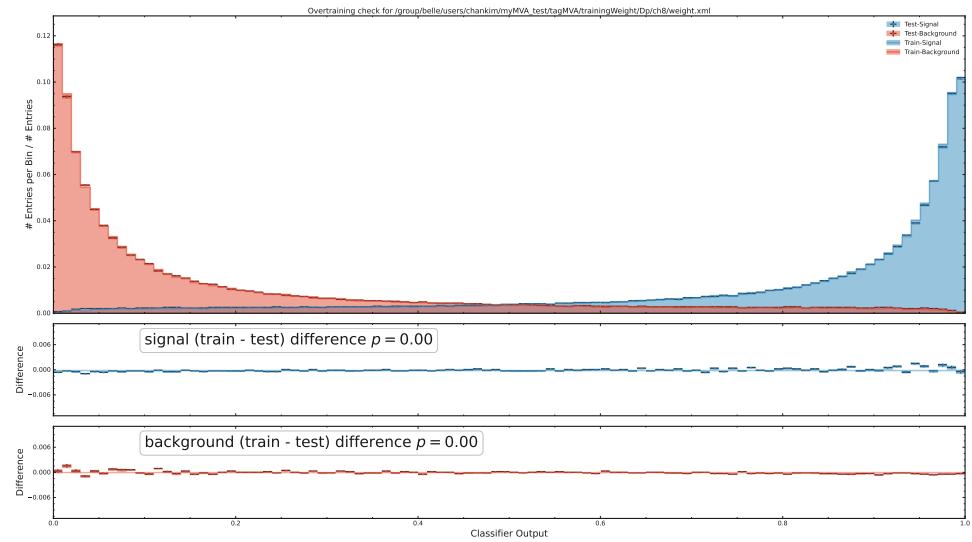


Figure 106: BDT output

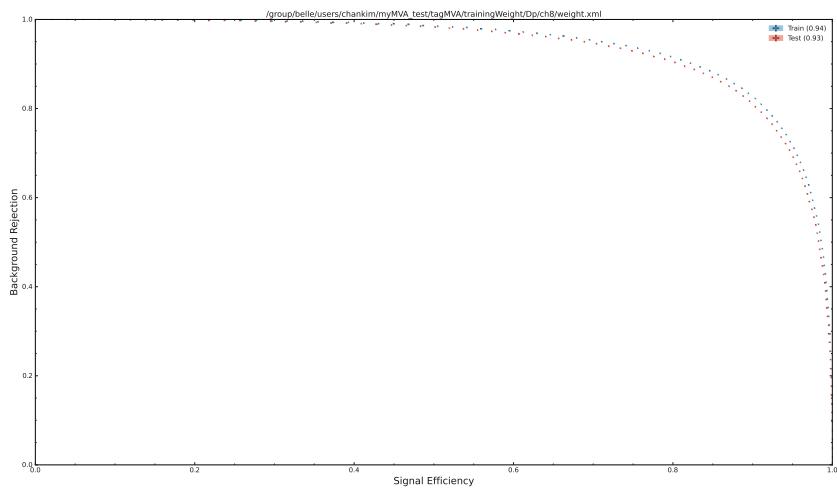


Figure 107: ROC Curve

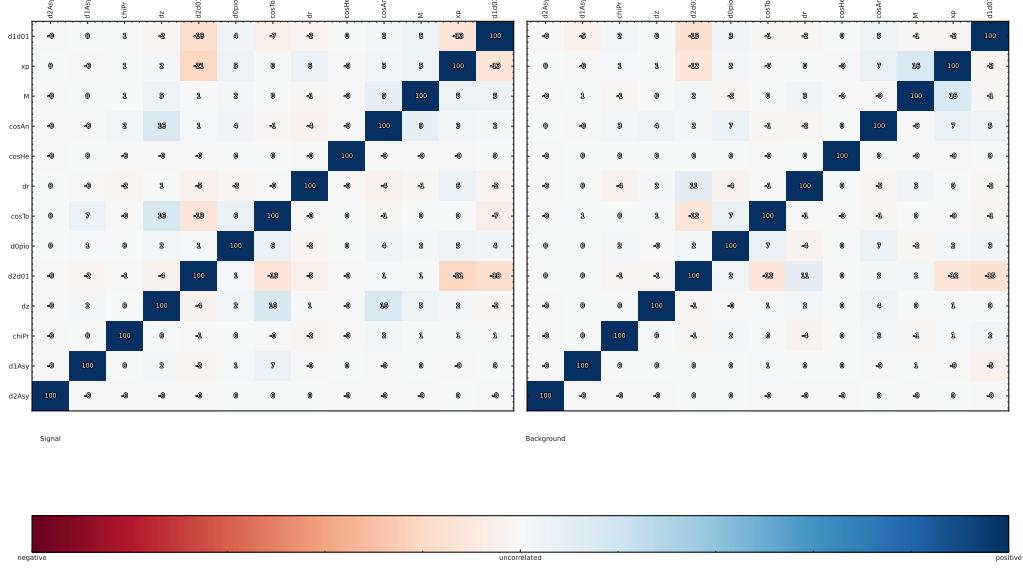


Figure 108: Correlation plot

402 A.1.25 $D^+ \rightarrow \pi^+\pi^-\pi^+K_S^0$

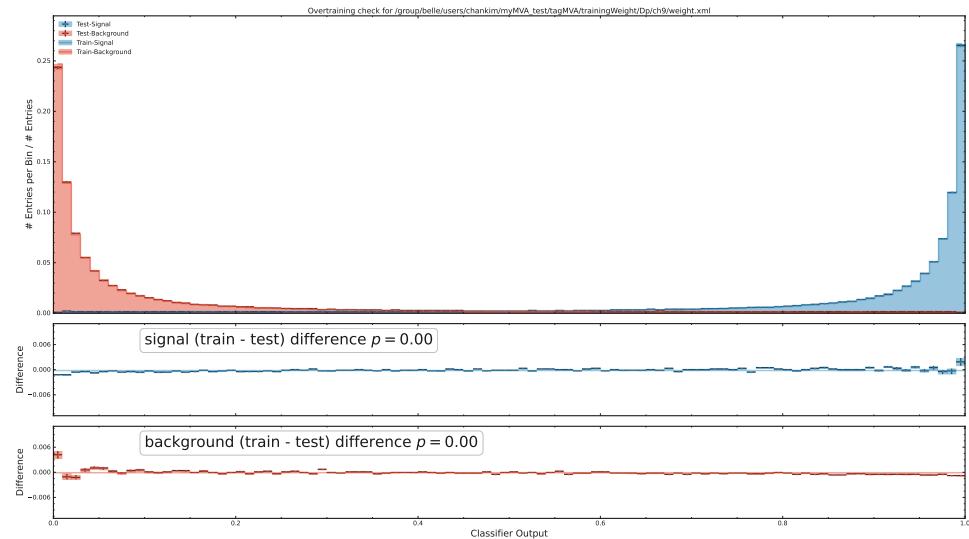


Figure 109: BDT output

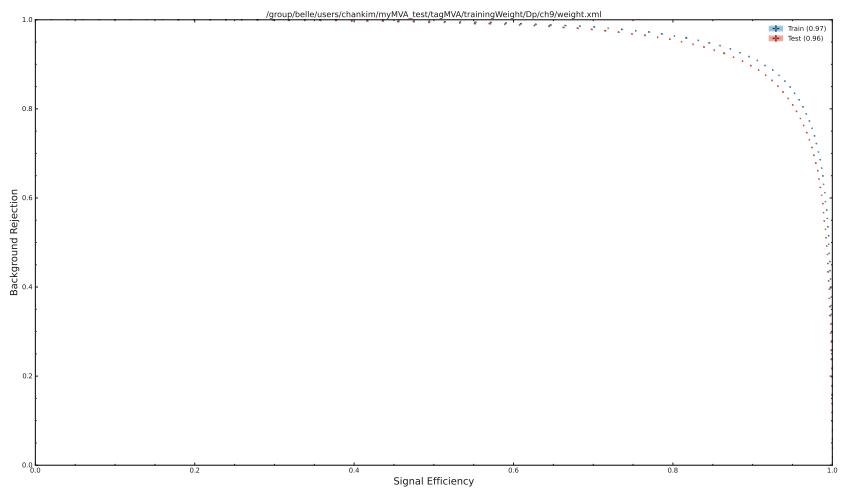


Figure 110: ROC Curve

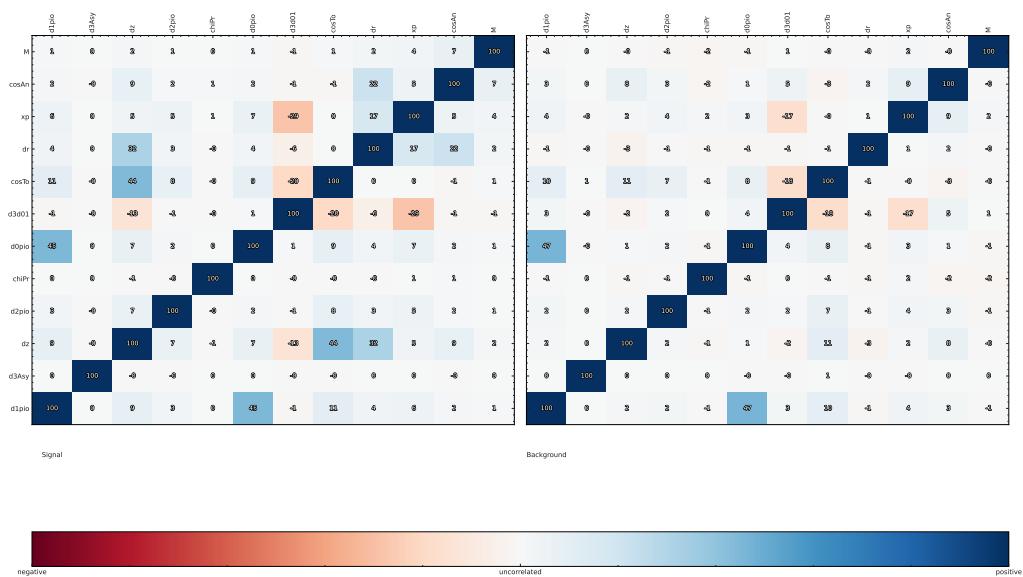


Figure 111: Correlation plot

403 A.1.26 $D^+ \rightarrow K^+ K_S^0 K_S^0$

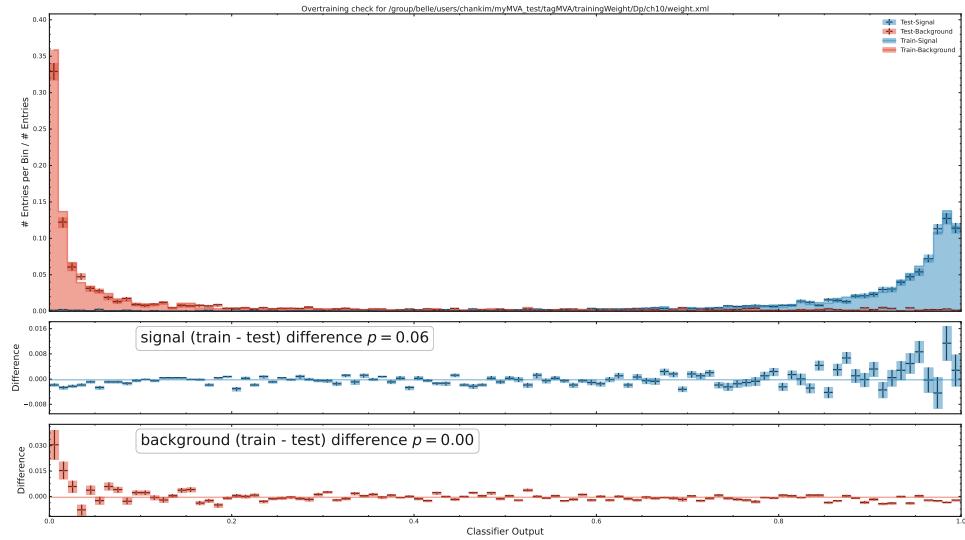


Figure 112: BDT output

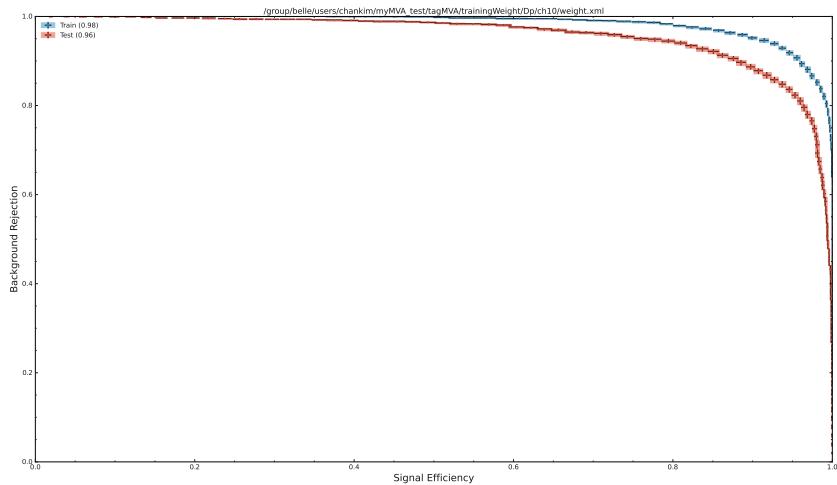


Figure 113: ROC Curve

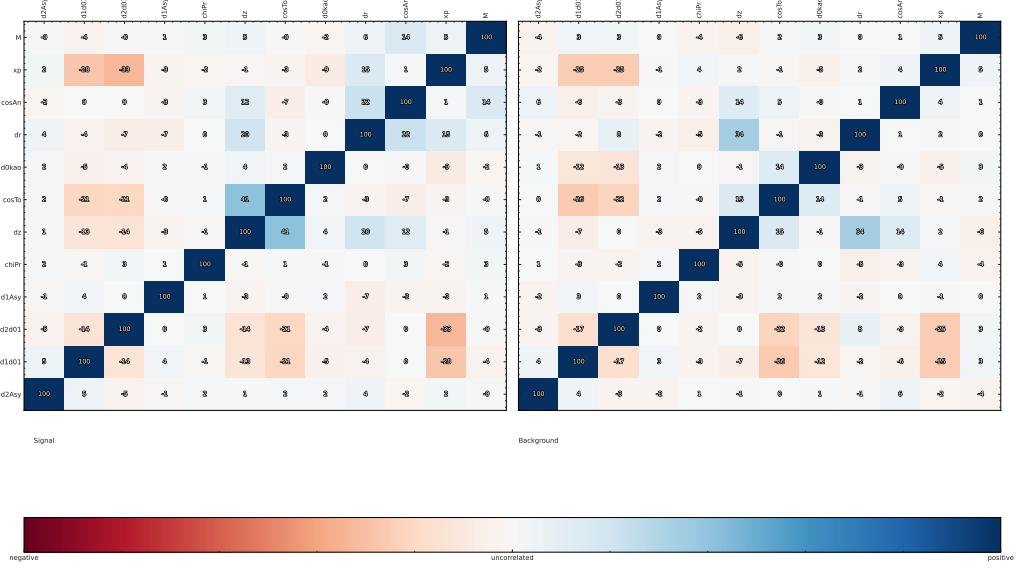


Figure 114: Correlation plot

404 A.1.27 $D_s^+ \rightarrow K^+ K^- \pi^+$

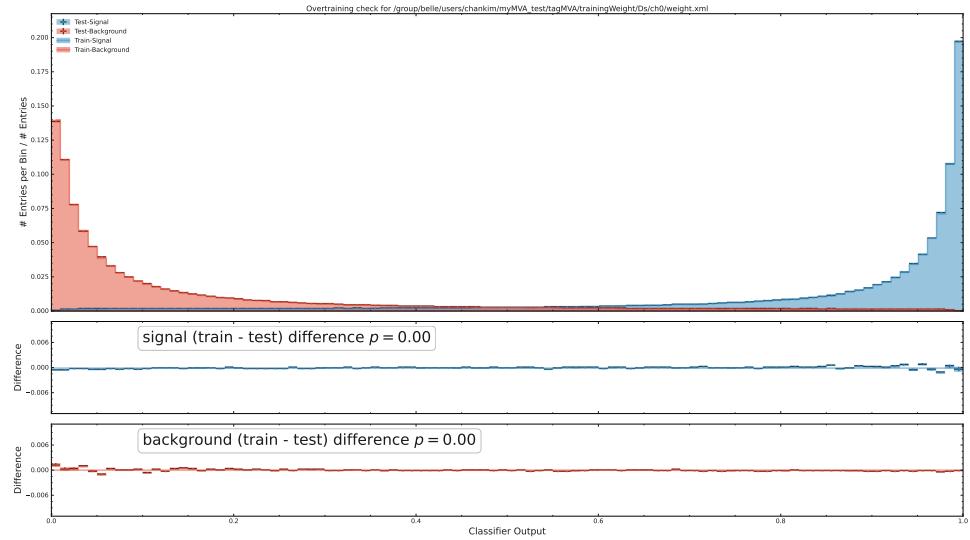


Figure 115: BDT output

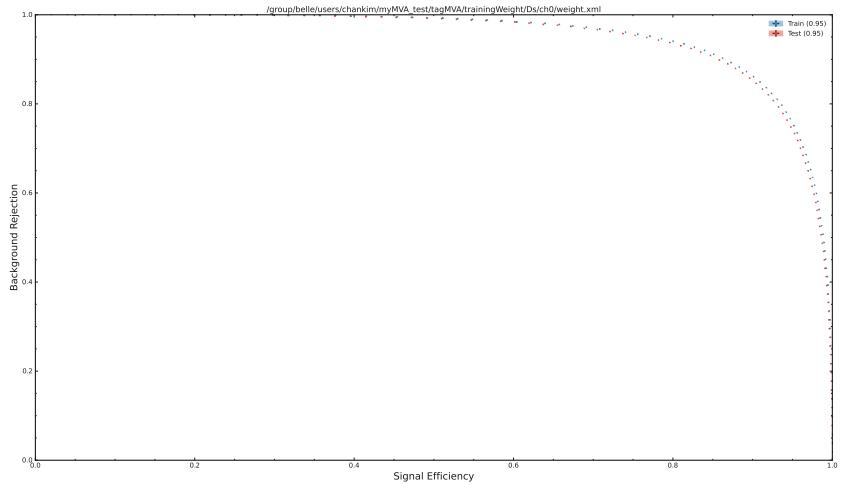


Figure 116: ROC Curve

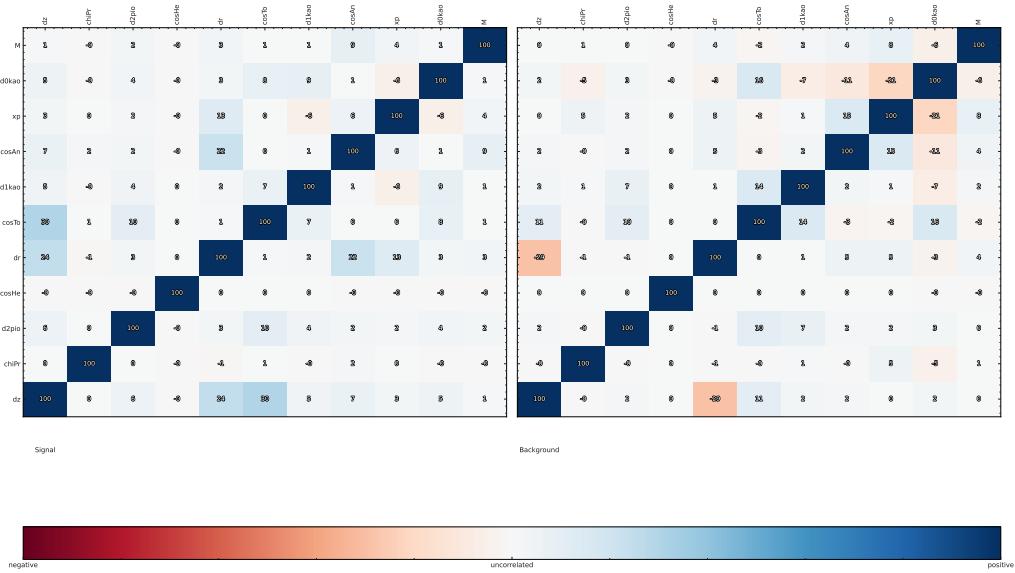


Figure 117: Correlation plot

405 A.1.28 $D_s^+ \rightarrow K^+ K_S^0$

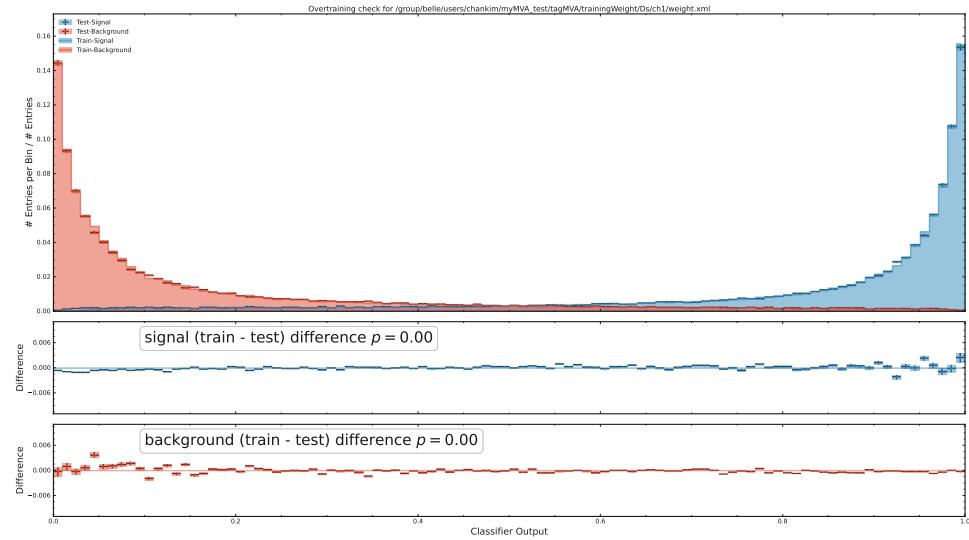


Figure 118: BDT output

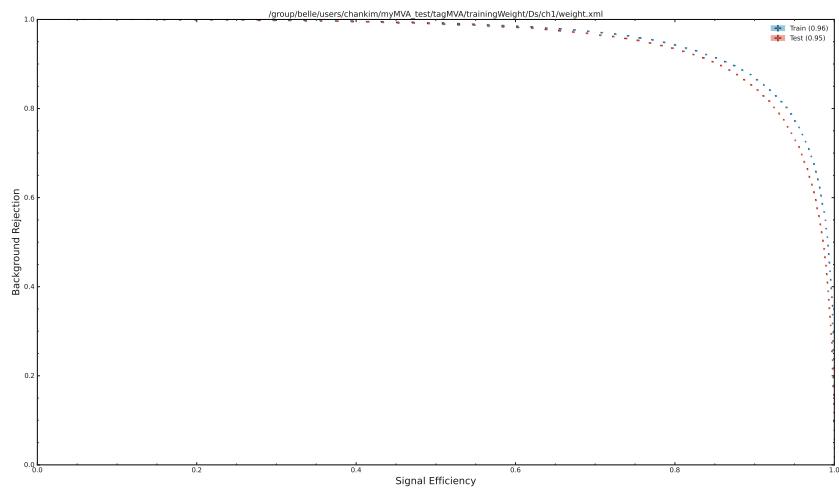


Figure 119: ROC Curve

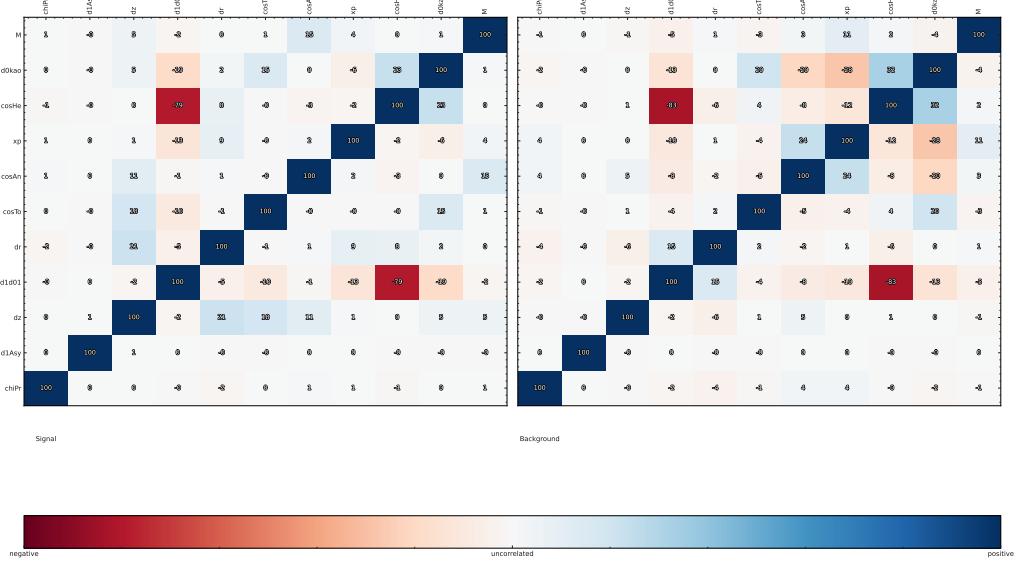


Figure 120: Correlation plot

406 A.1.29 $D_s^+ \rightarrow \pi^+ K_S^0 K_S^0$

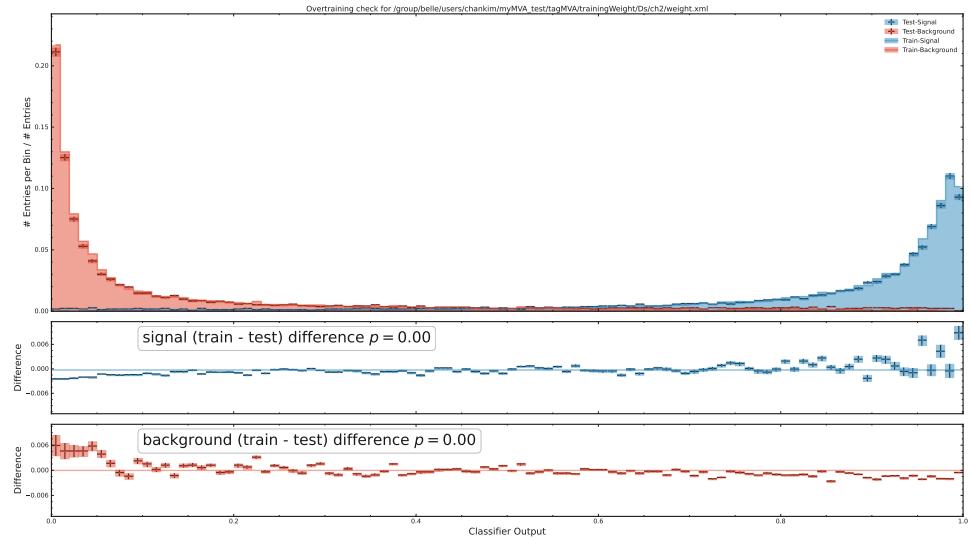


Figure 121: BDT output

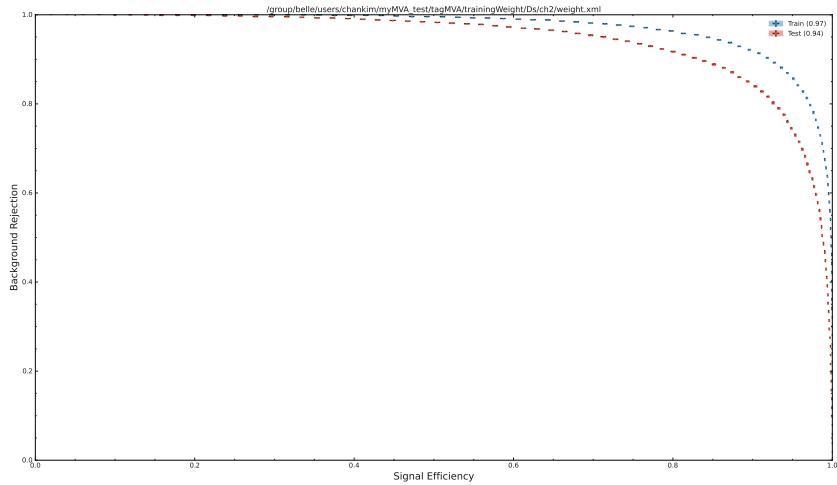
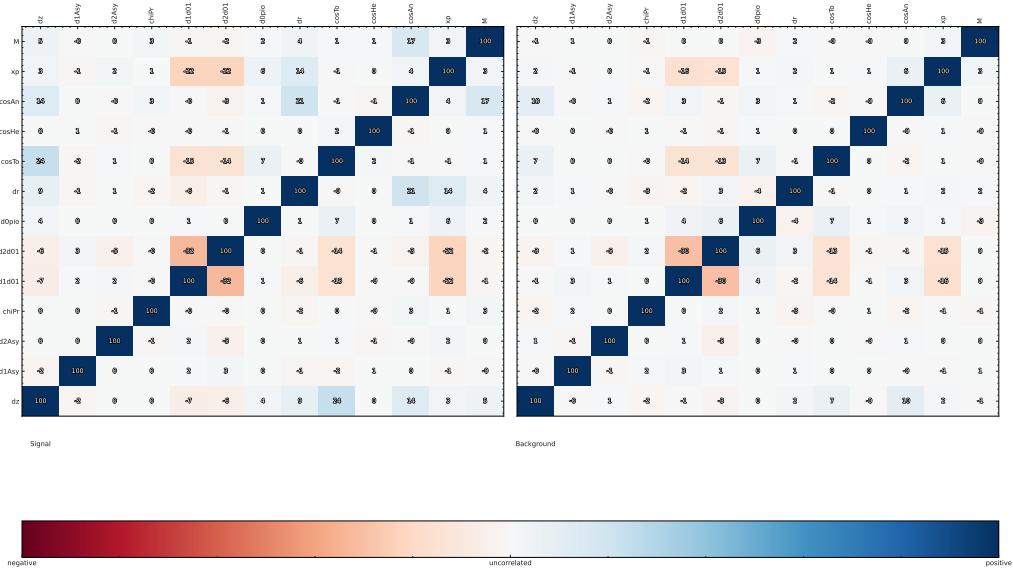


Figure 122: ROC Curve



407 A.1.30 $D_s^+ \rightarrow K^+ K^- \pi^+ \pi^0$

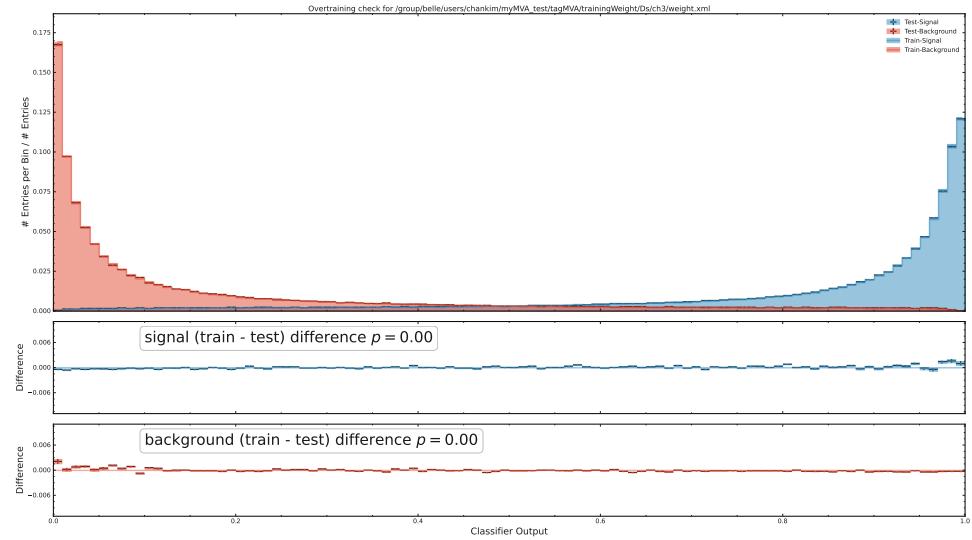


Figure 124: BDT output

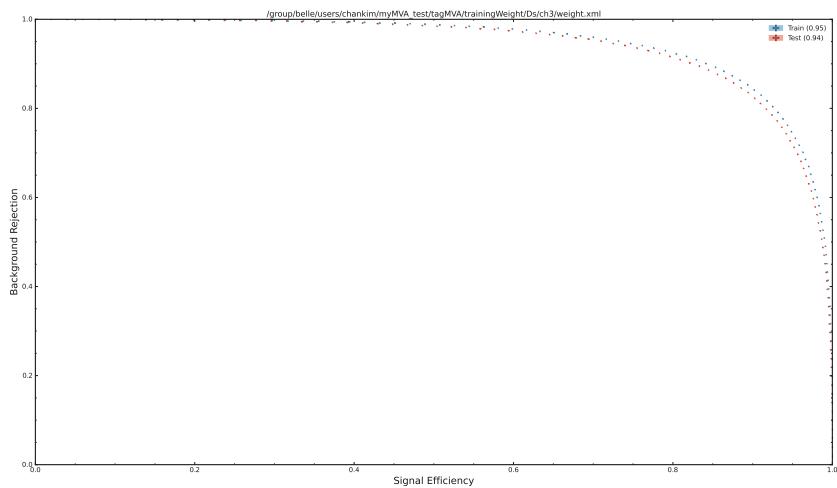


Figure 125: ROC Curve

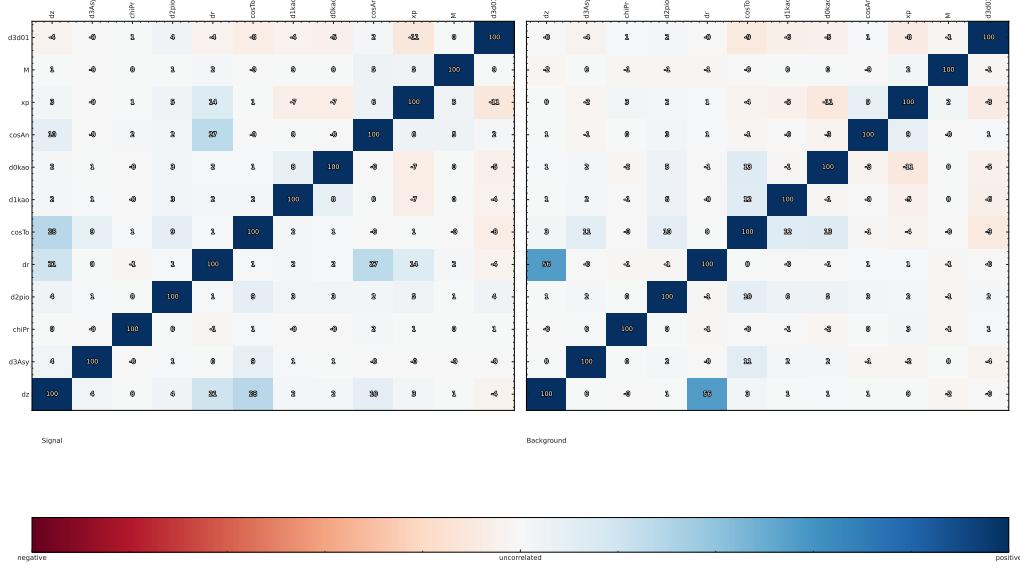


Figure 126: Correlation plot

408 A.1.31 $D_s^+ \rightarrow K^- \pi^+ \pi^+ K_S^0$

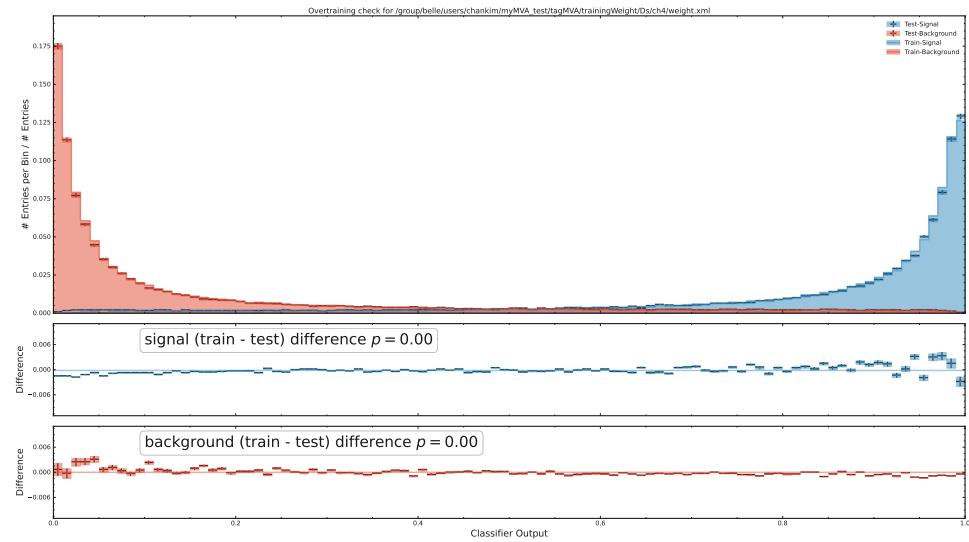


Figure 127: BDT output

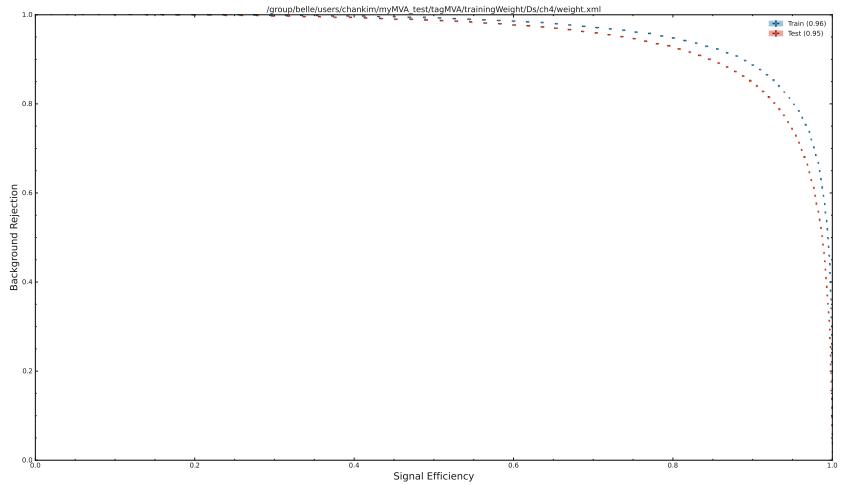


Figure 128: ROC Curve

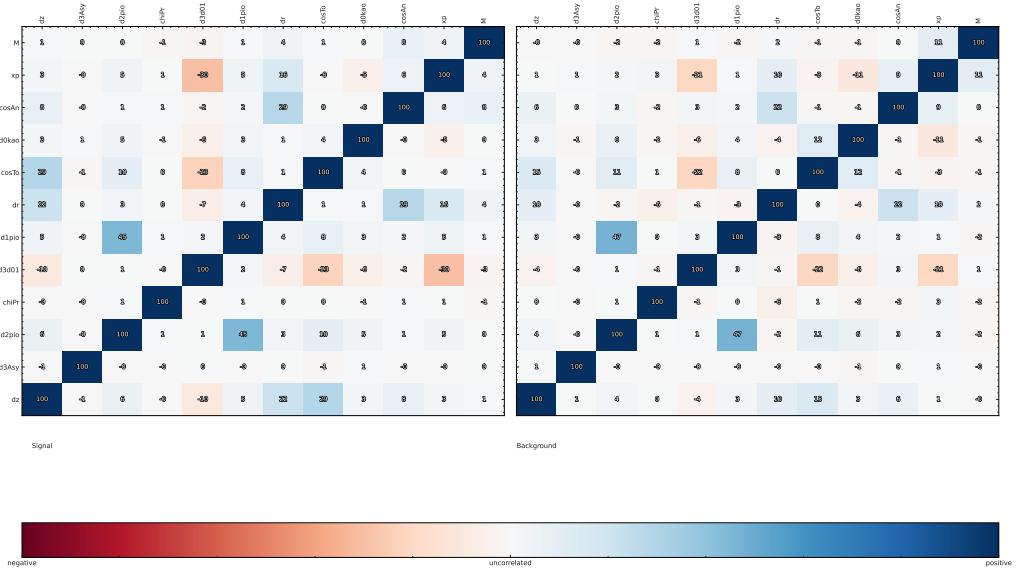


Figure 129: Correlation plot

409 A.1.32 $D_s^+ \rightarrow K^+ \pi^+ \pi^- K_S^0$

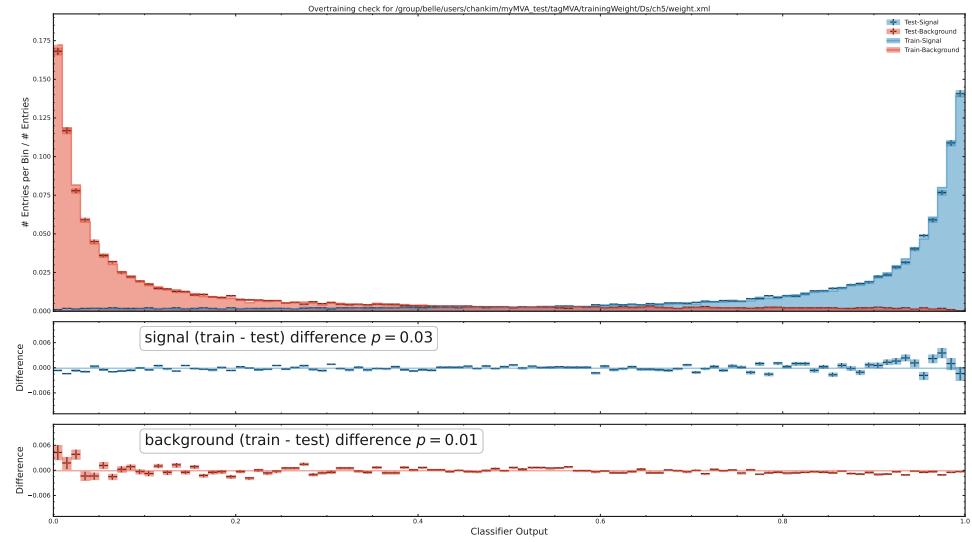


Figure 130: BDT output

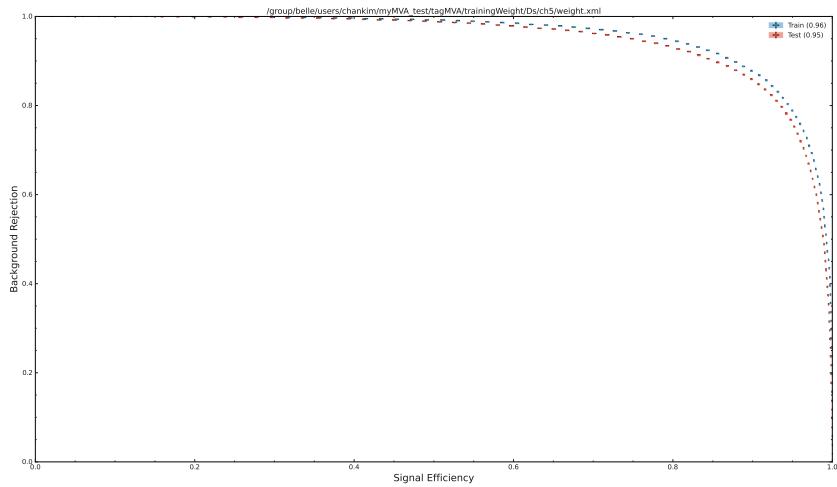


Figure 131: ROC Curve

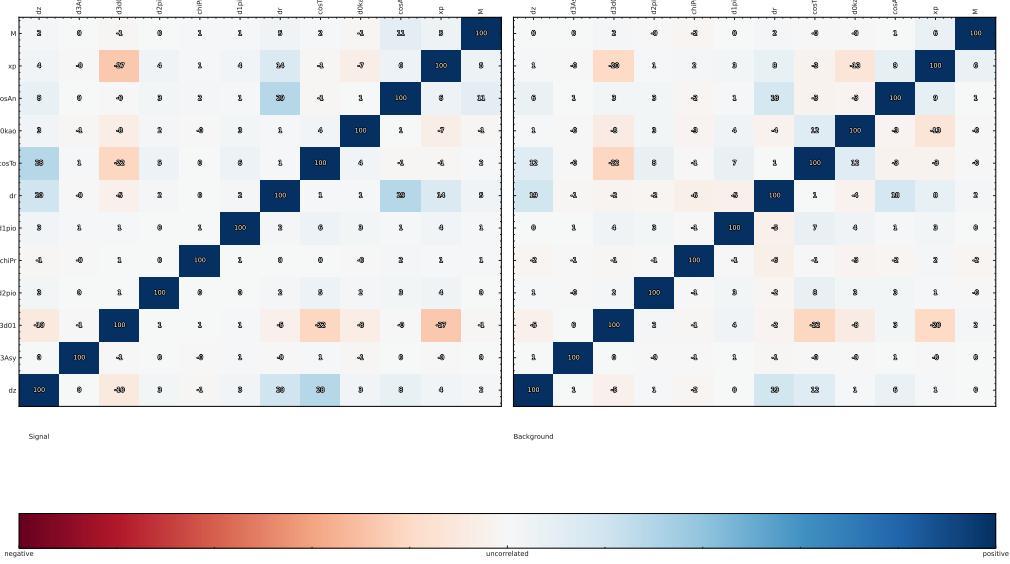


Figure 132: Correlation plot

410 A.1.33 $D_s^+ \rightarrow \pi^+ \pi^- \pi^+$

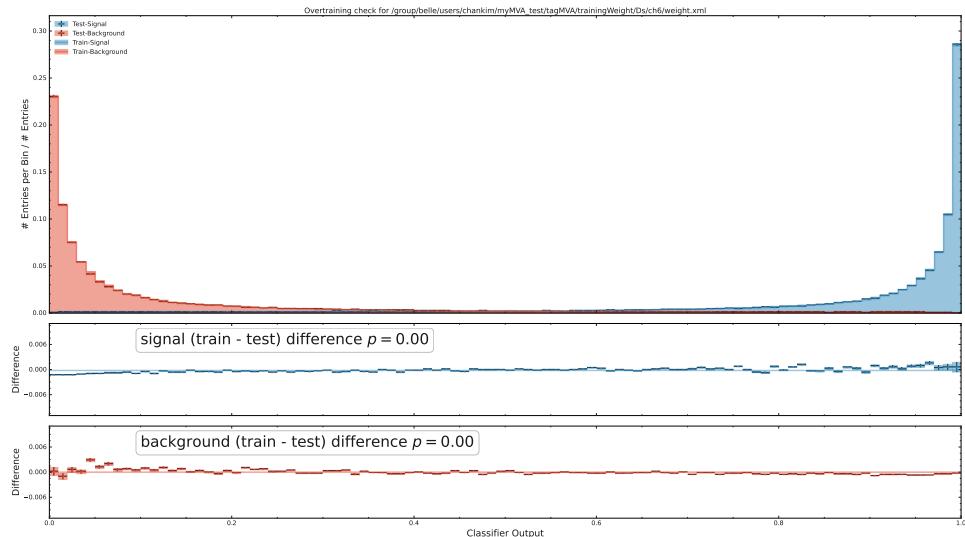


Figure 133: BDT output

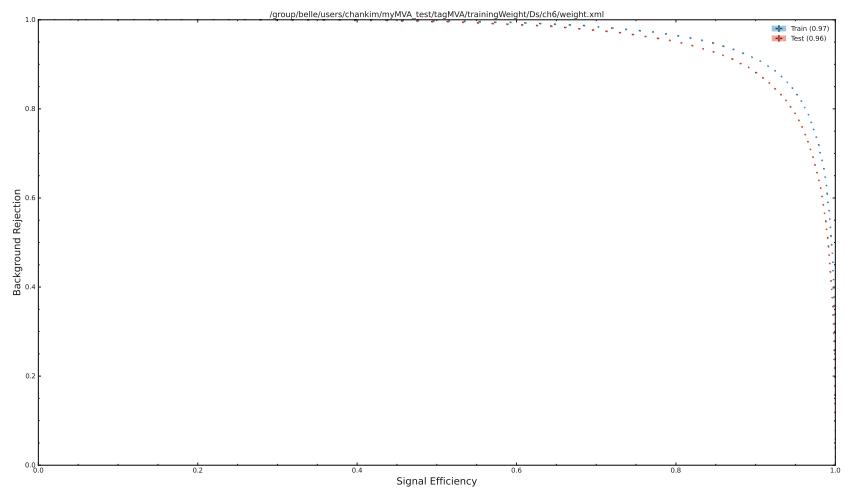


Figure 134: ROC Curve

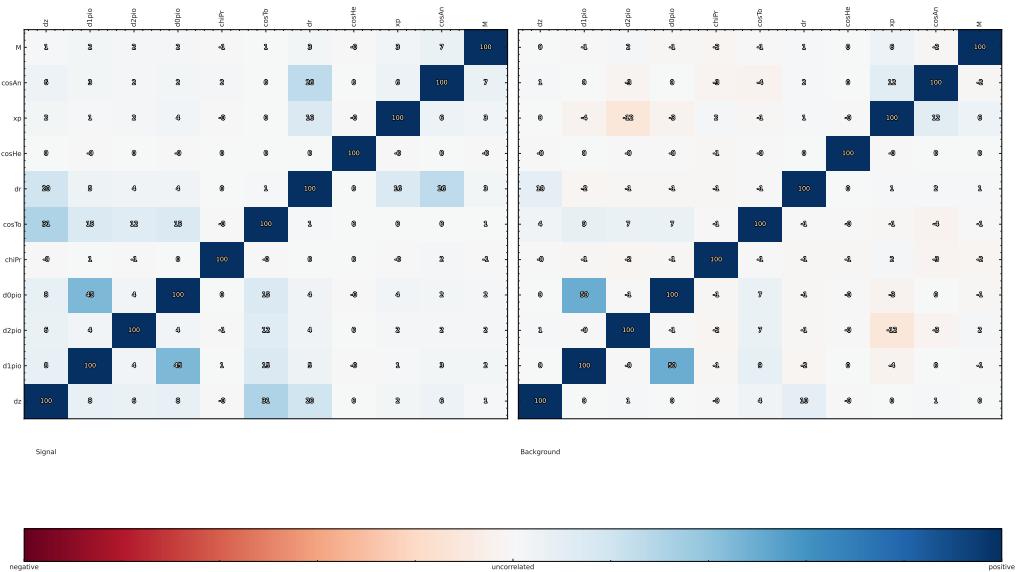


Figure 135: Correlation plot

411 A.1.34 $D_s^+ \rightarrow \pi^+ K_S^0$

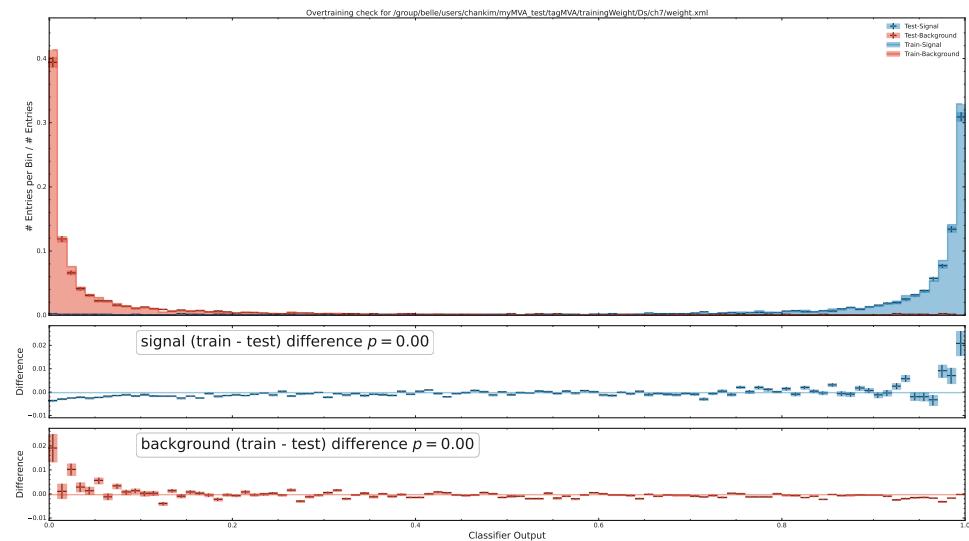


Figure 136: BDT output

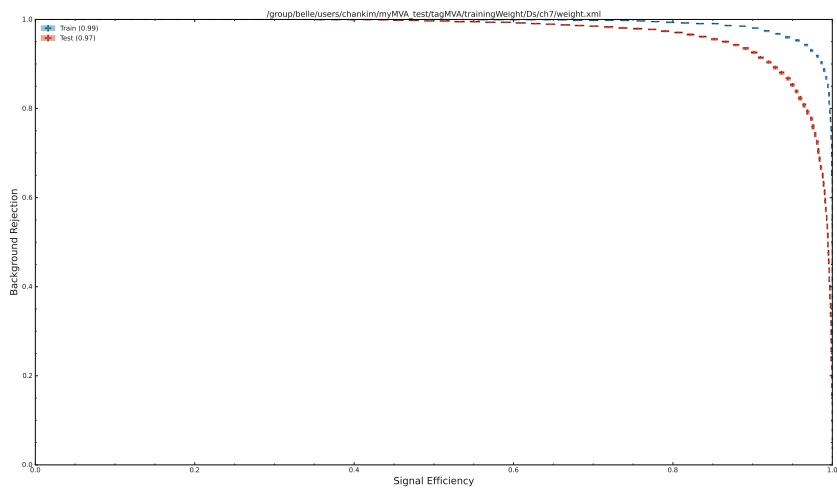


Figure 137: ROC Curve

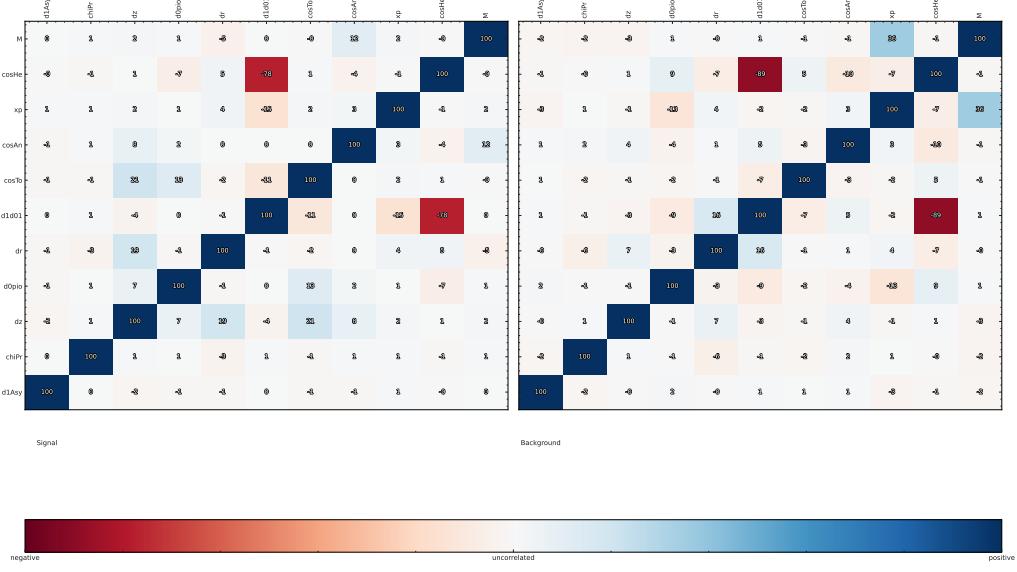


Figure 138: Correlation plot

412 A.1.35 $D_s^+ \rightarrow \pi^+ \pi^0 K_S^0$

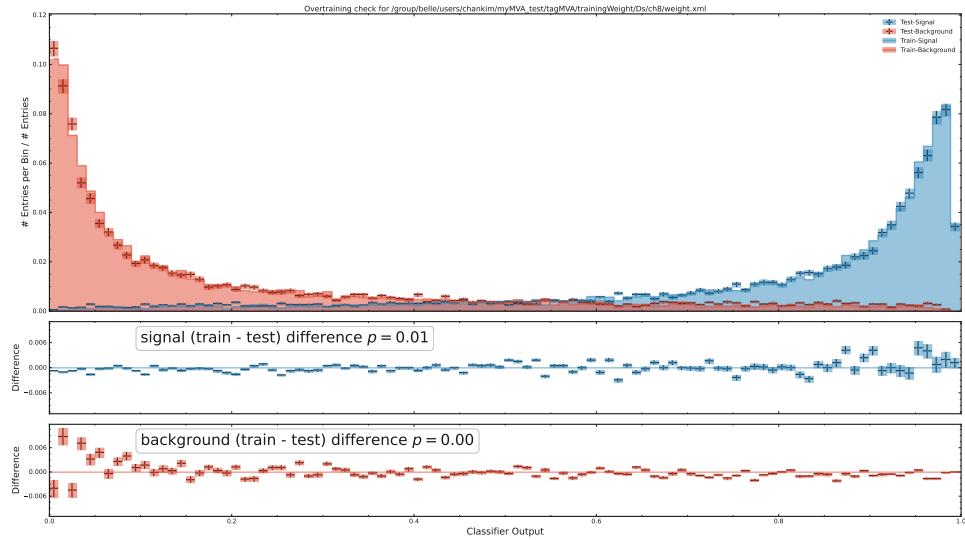


Figure 139: BDT output

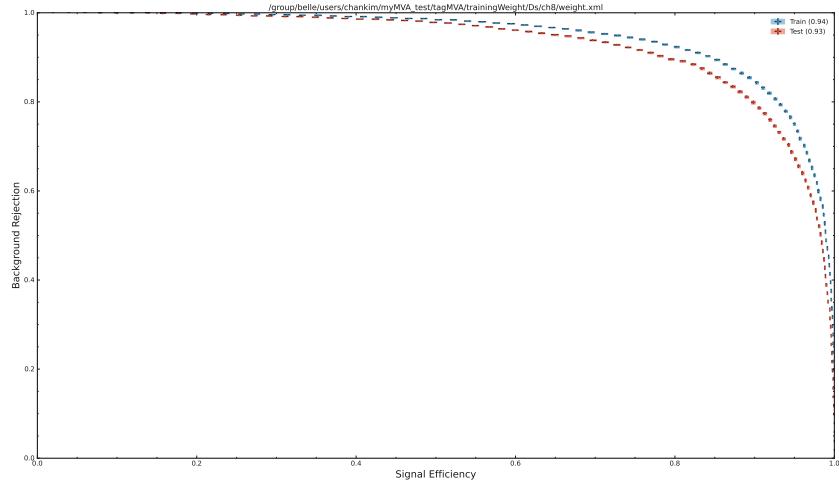


Figure 140: ROC Curve

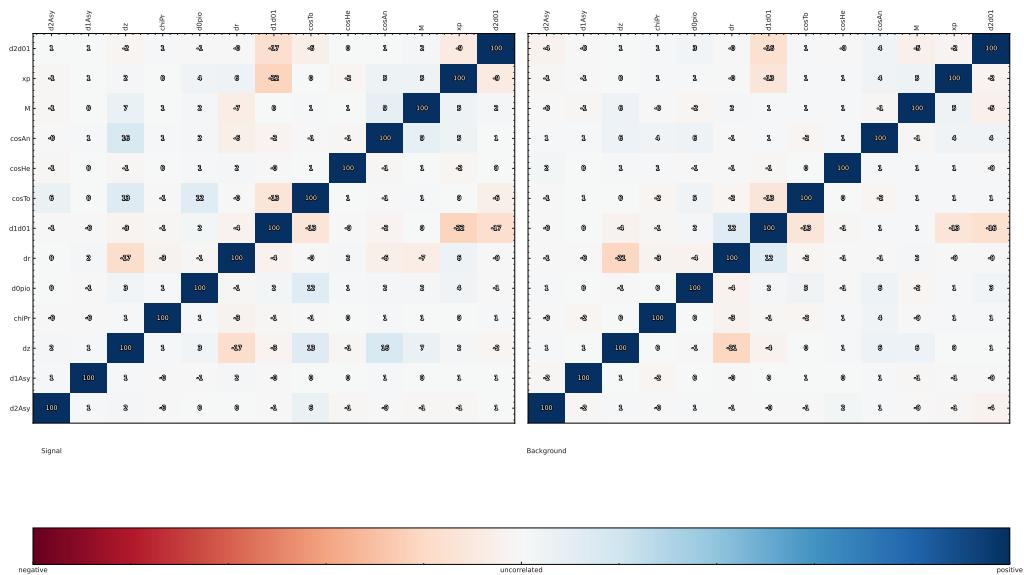


Figure 141: Correlation plot

413 A.1.36 $D_s^+ \rightarrow K^+ K^- \pi^+ \pi^- \pi^+$

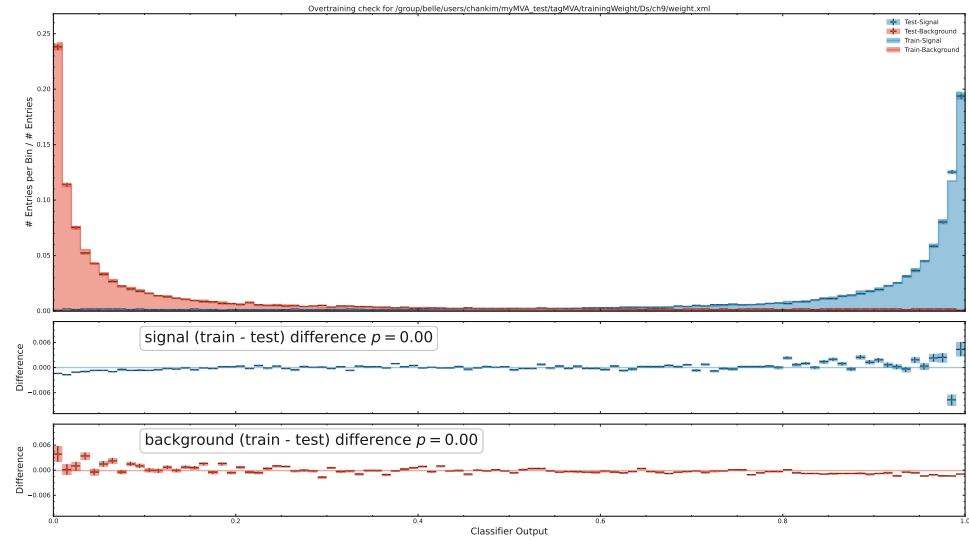


Figure 142: BDT output

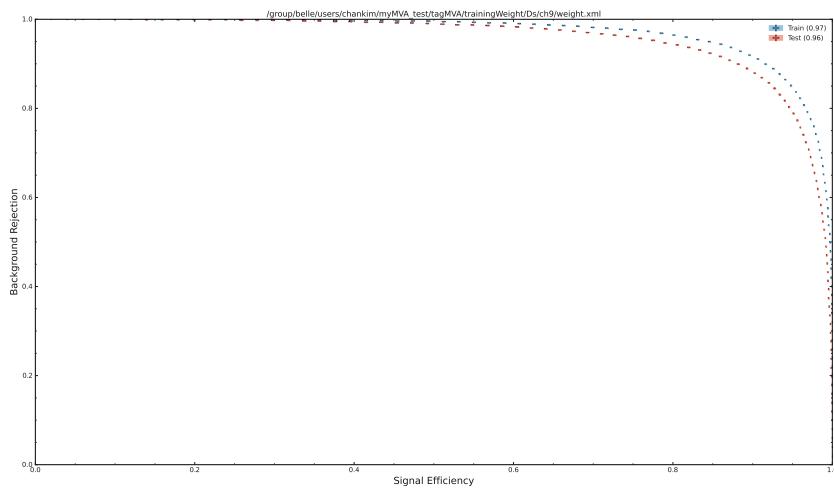


Figure 143: ROC Curve

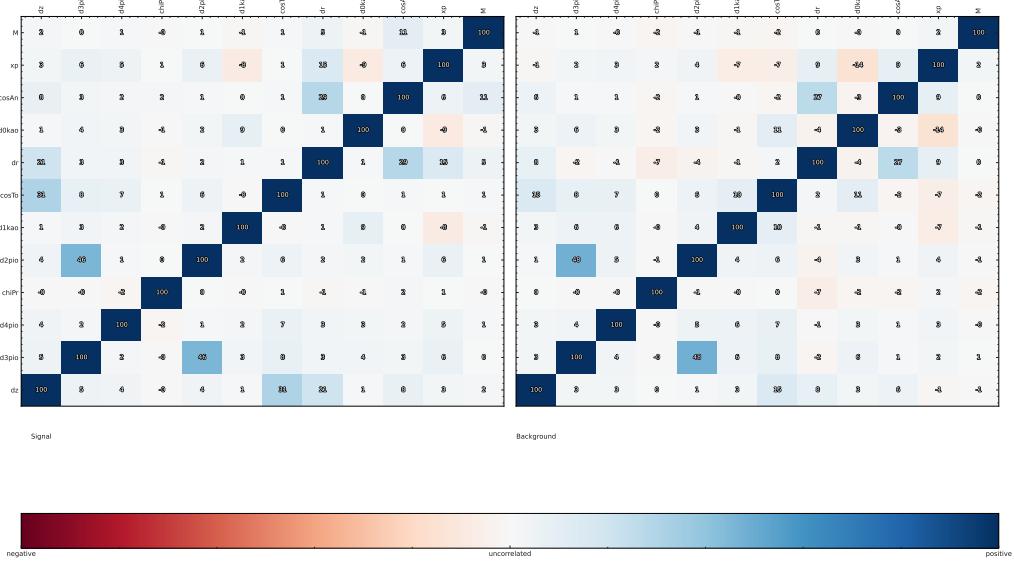


Figure 144: Correlation plot

414 A.1.37 $\Lambda_c^+ \rightarrow p^+ K^- \pi^+$

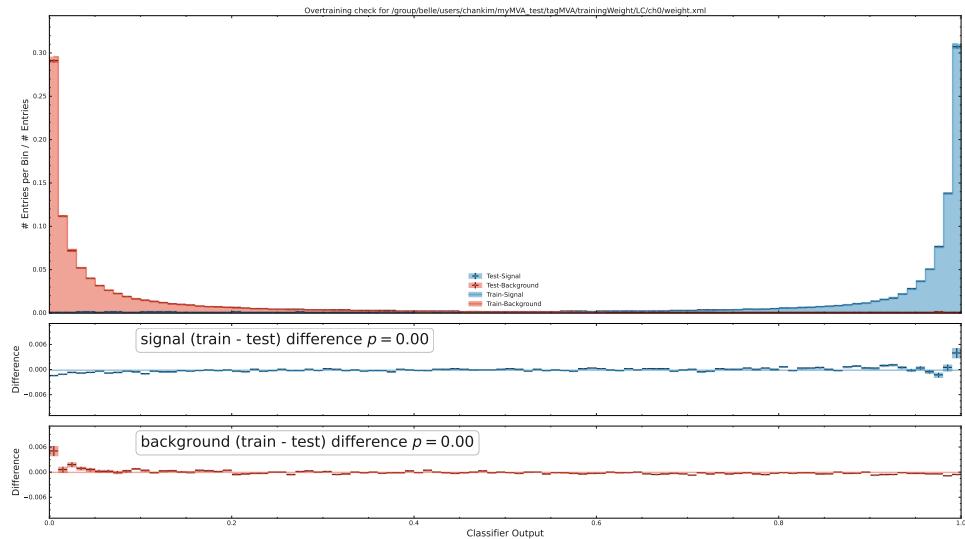


Figure 145: BDT output

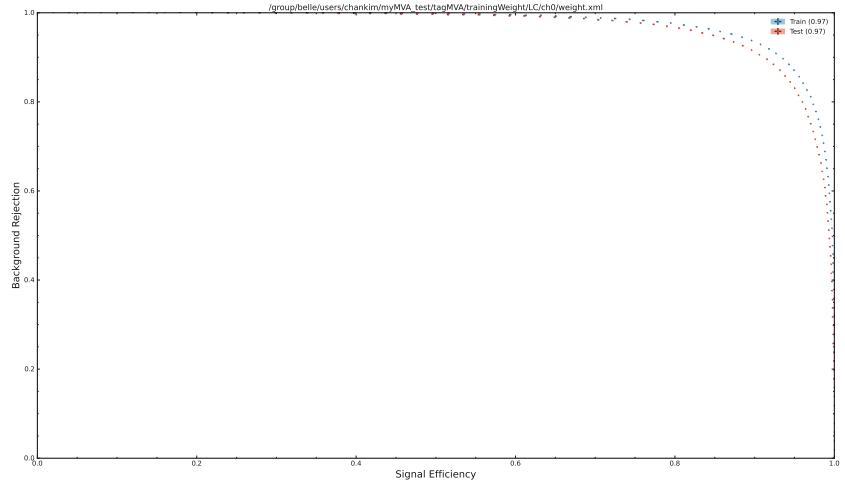


Figure 146: ROC Curve

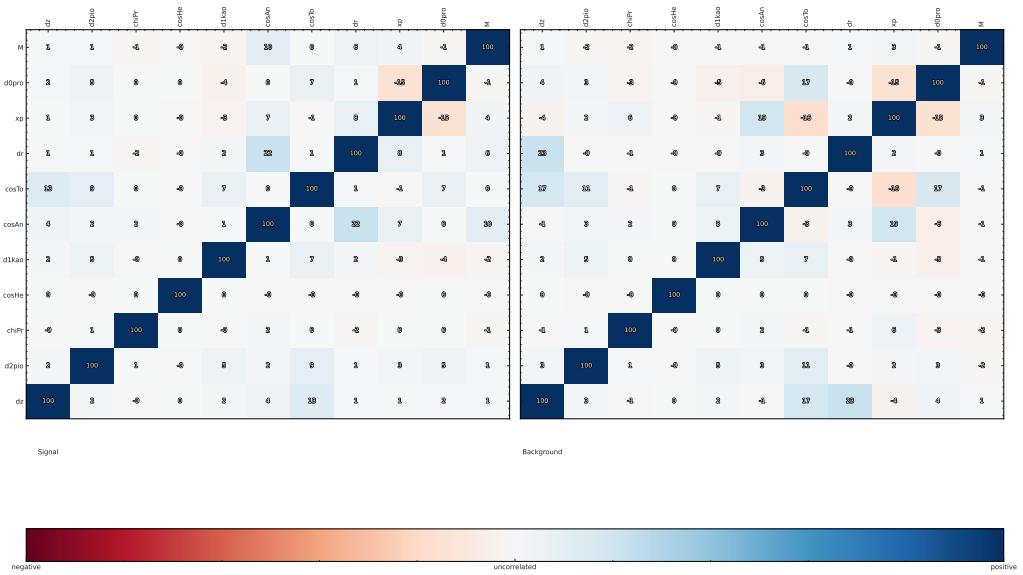


Figure 147: Correlation plot

415 A.1.38 $\Lambda_c^+ \rightarrow p^+ \pi^- \pi^+$

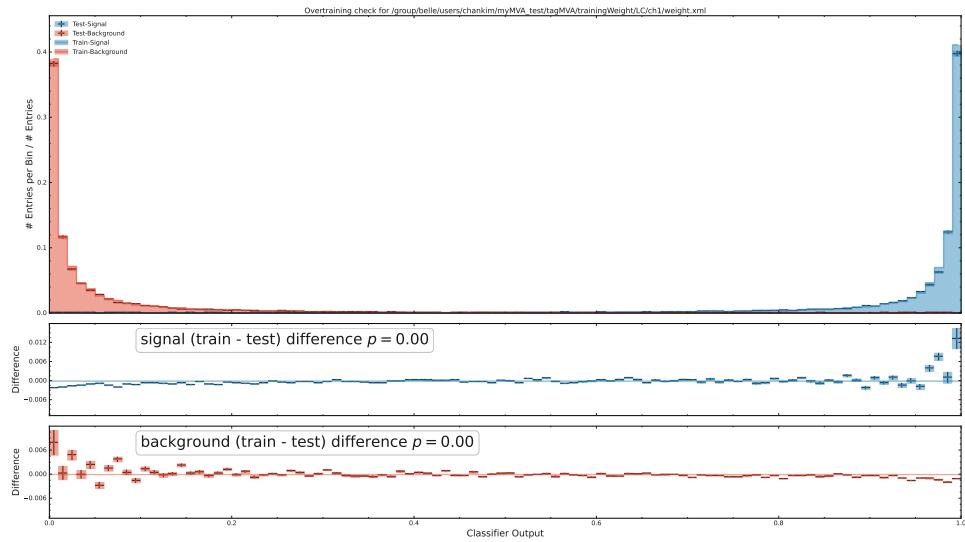


Figure 148: BDT output

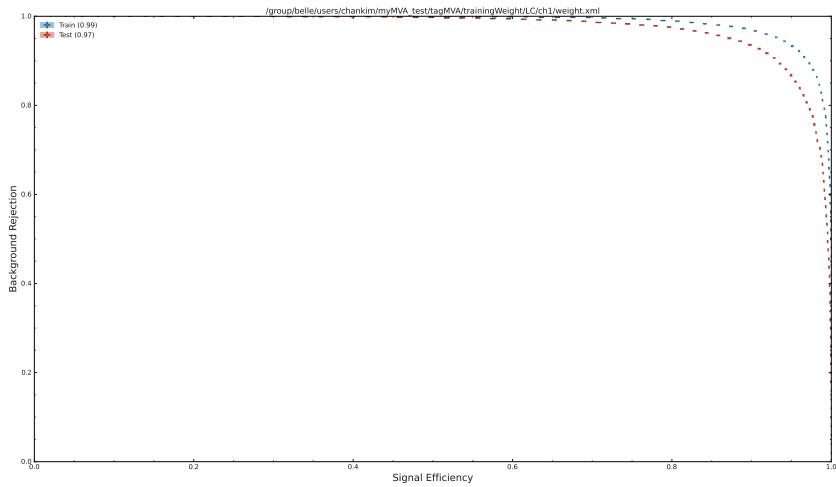


Figure 149: ROC Curve

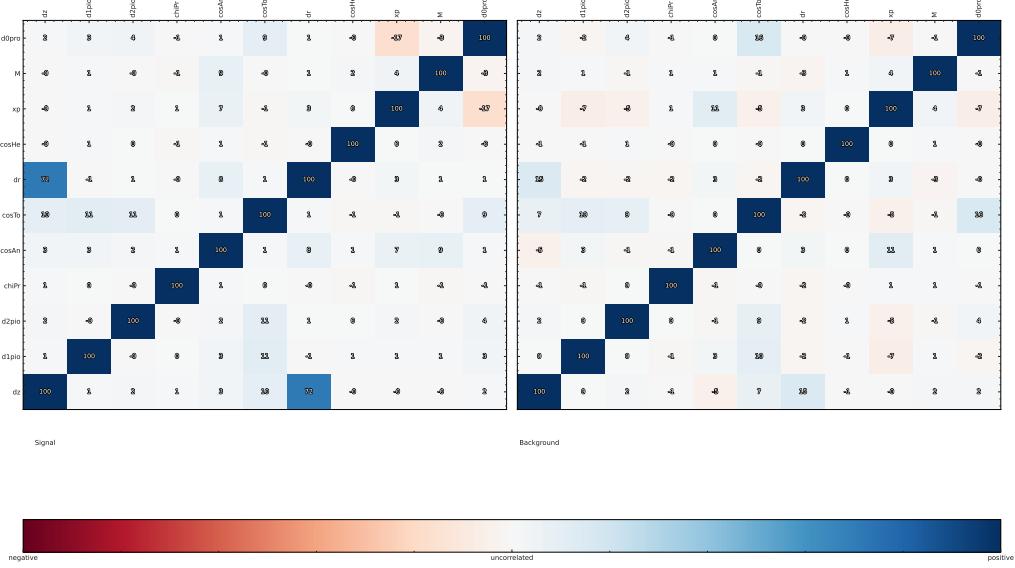


Figure 150: Correlation plot

416 A.1.39 $\Lambda_c^+ \rightarrow p^+ K^- K^+$

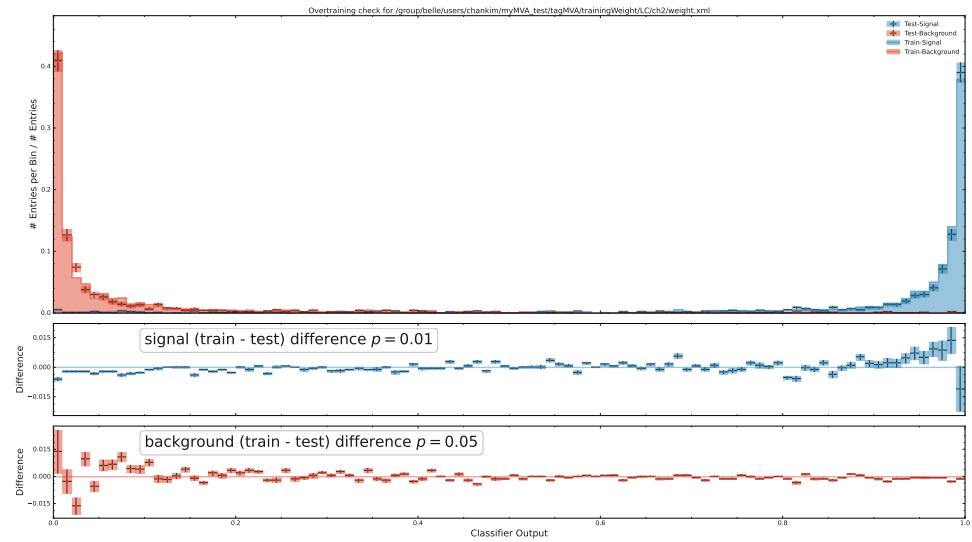


Figure 151: BDT output

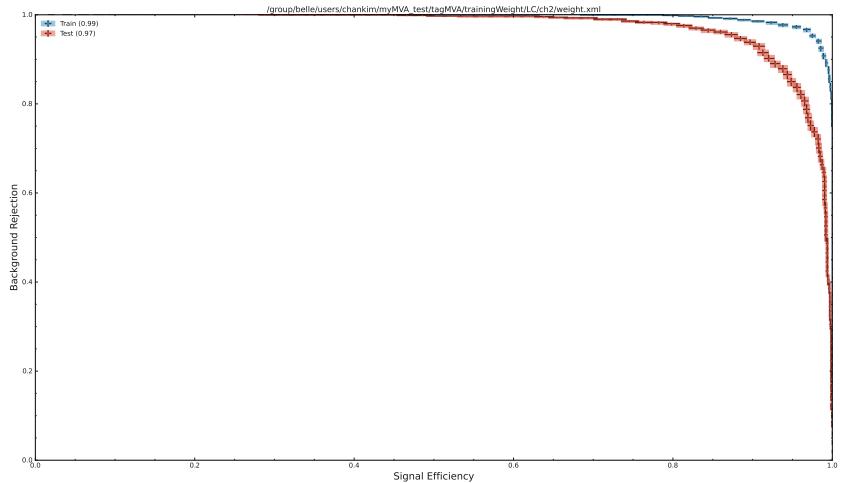


Figure 152: ROC Curve

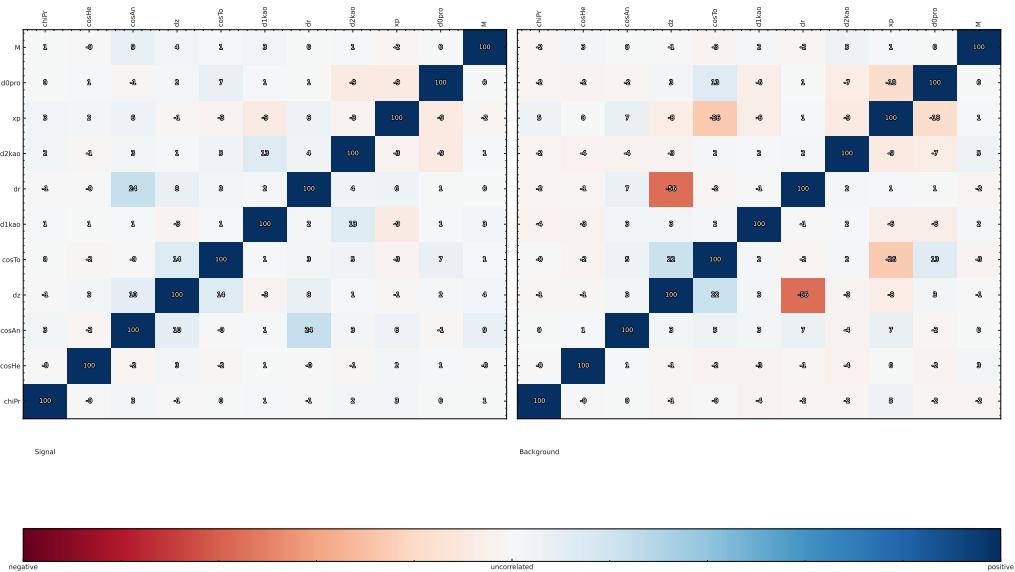


Figure 153: Correlation plot

417 A.1.40 $\Lambda_c^+ \rightarrow p^+ K^- \pi^+ \pi^0$

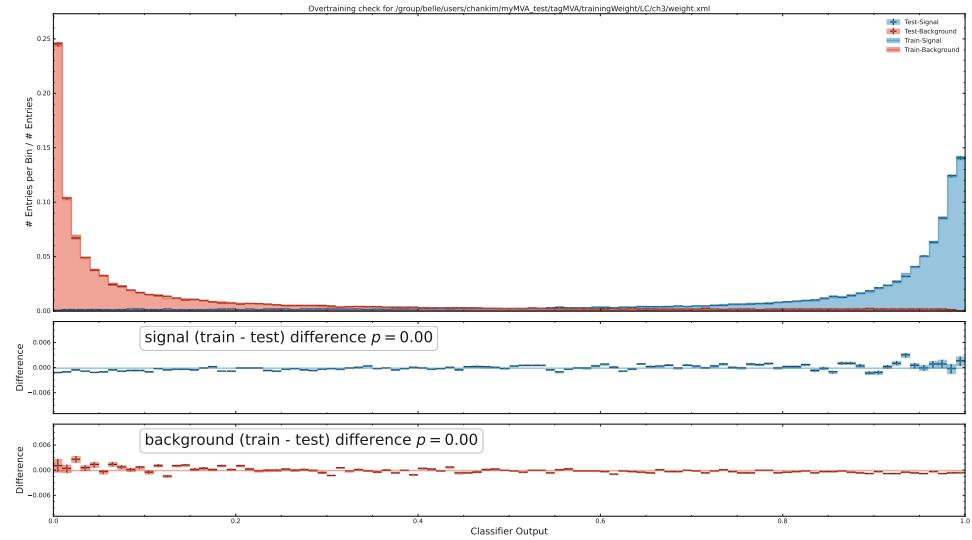


Figure 154: BDT output

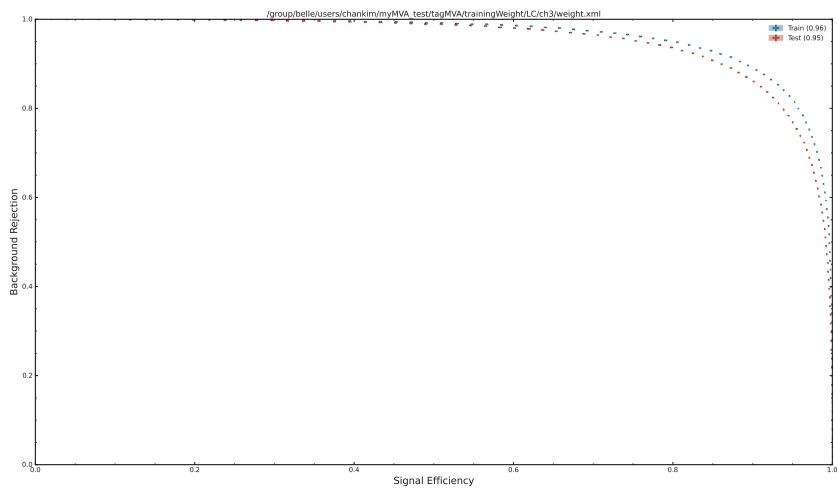


Figure 155: ROC Curve

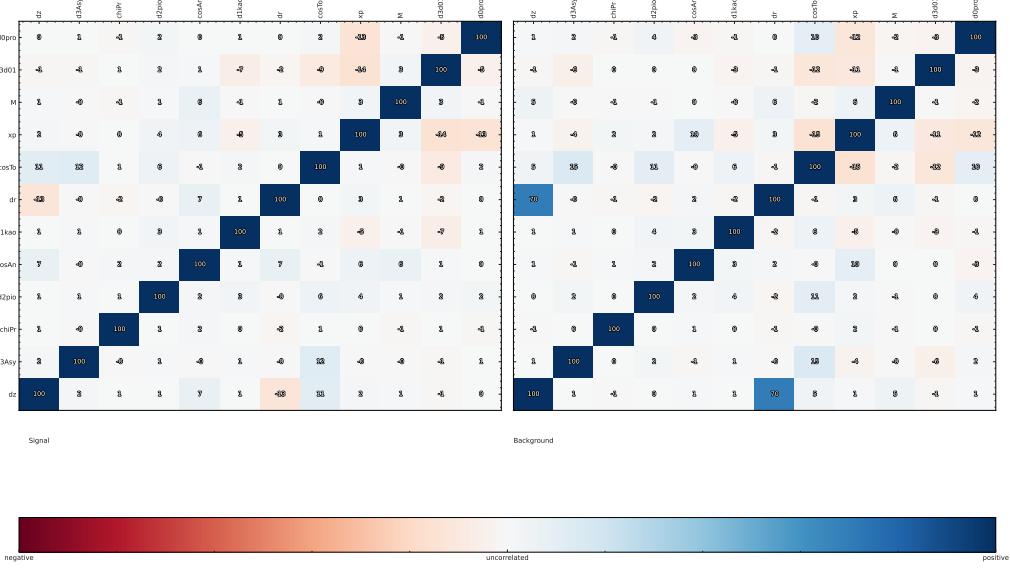


Figure 156: Correlation plot

418 A.1.41 $\Lambda_c^+ \rightarrow p^+ K^- \pi^+ \pi^0 \pi^0$

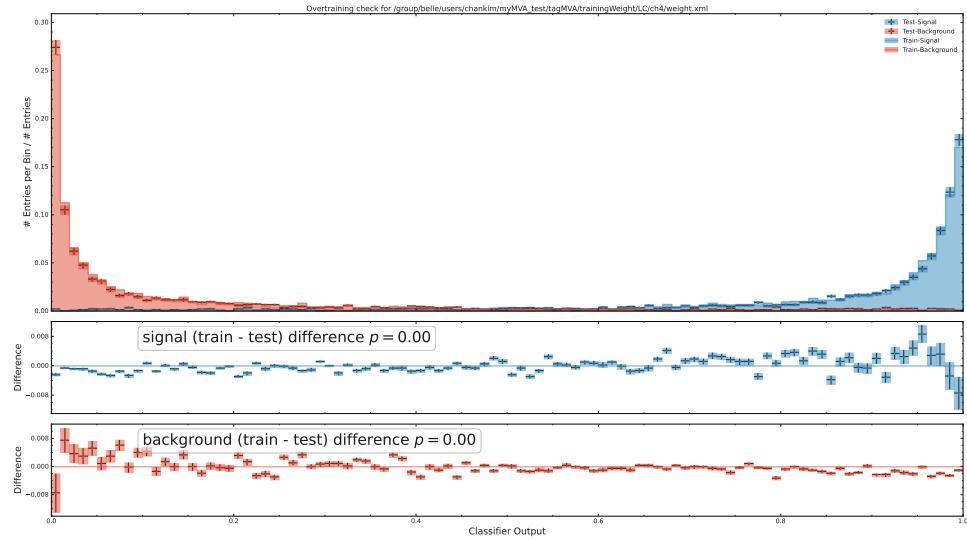


Figure 157: BDT output

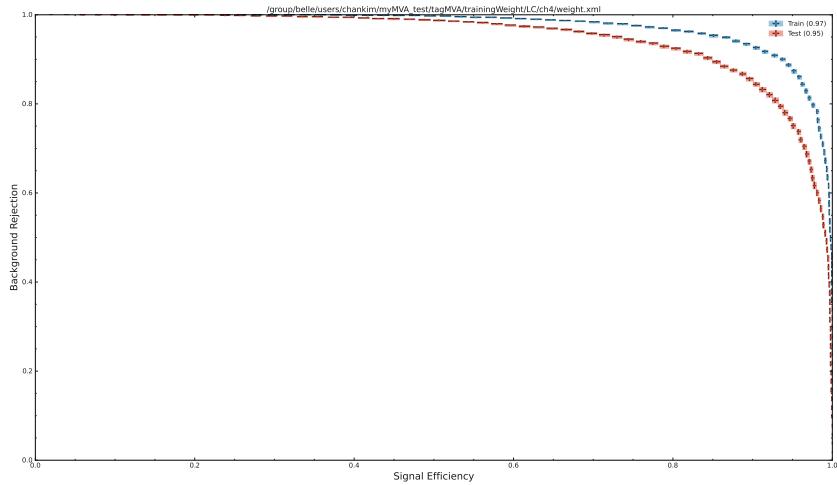


Figure 158: ROC Curve

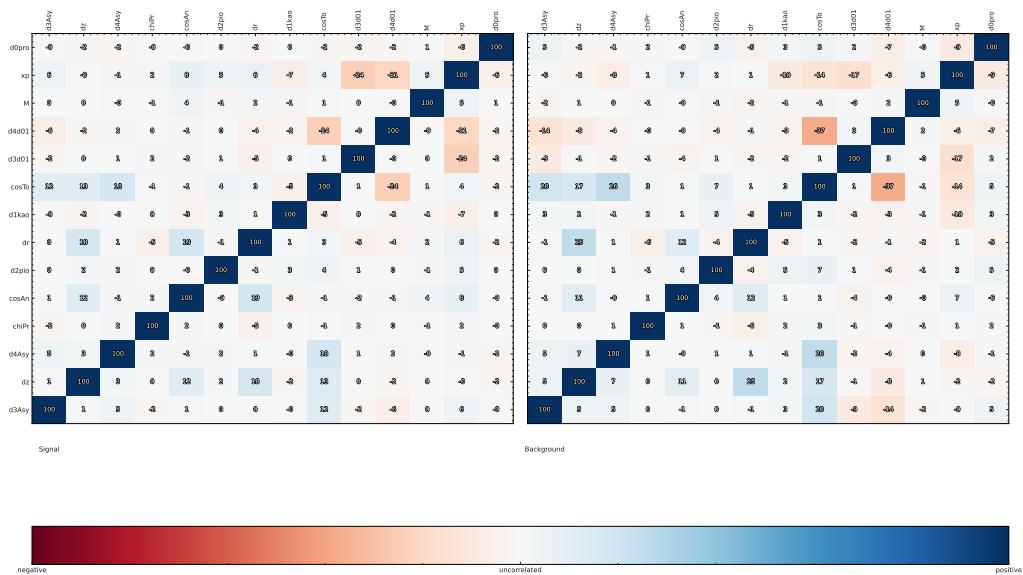


Figure 159: Correlation plot

419 A.1.42 $\Lambda_c^+ \rightarrow p^+ \pi^- \pi^+ \pi^- \pi^+$

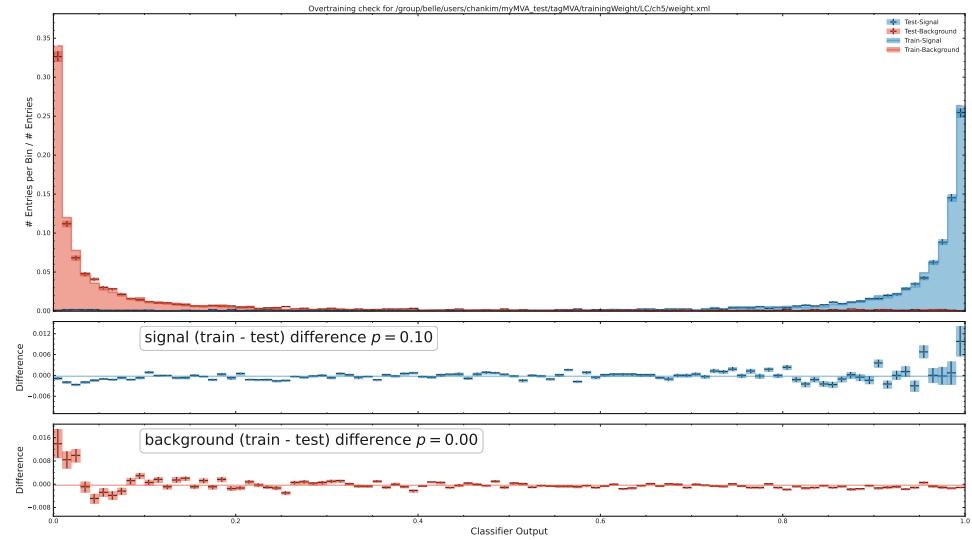


Figure 160: BDT output

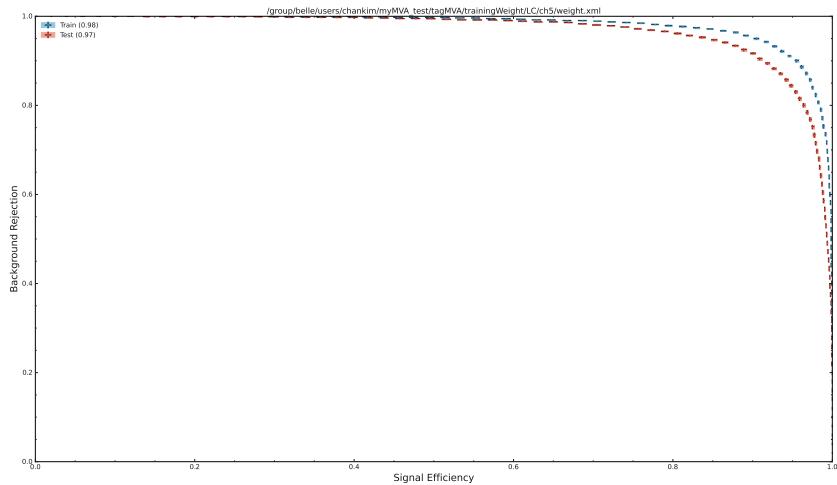


Figure 161: ROC Curve

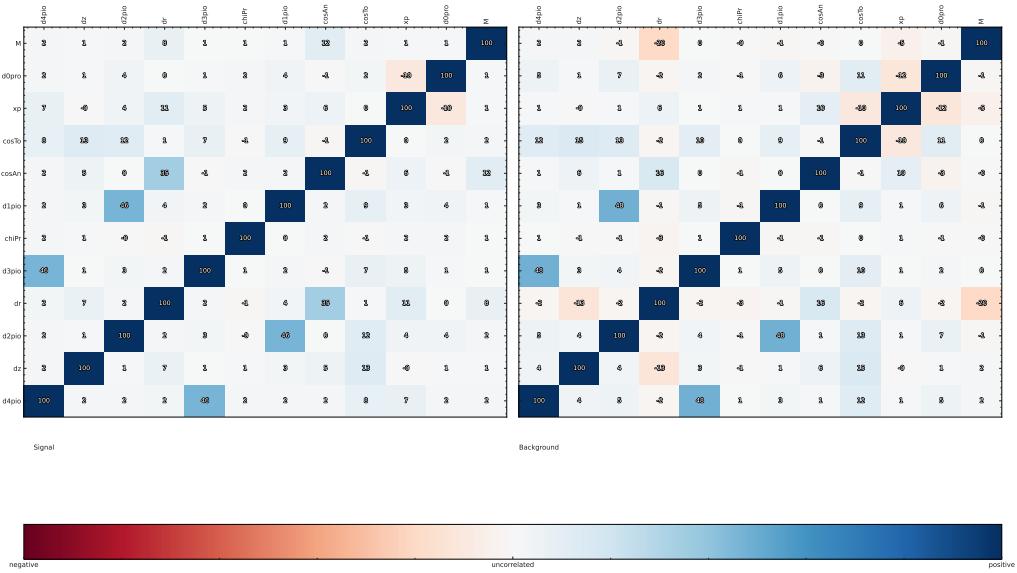


Figure 162: Correlation plot

420 A.1.43 $\Lambda_c^+ \rightarrow p^+ K_S^0$

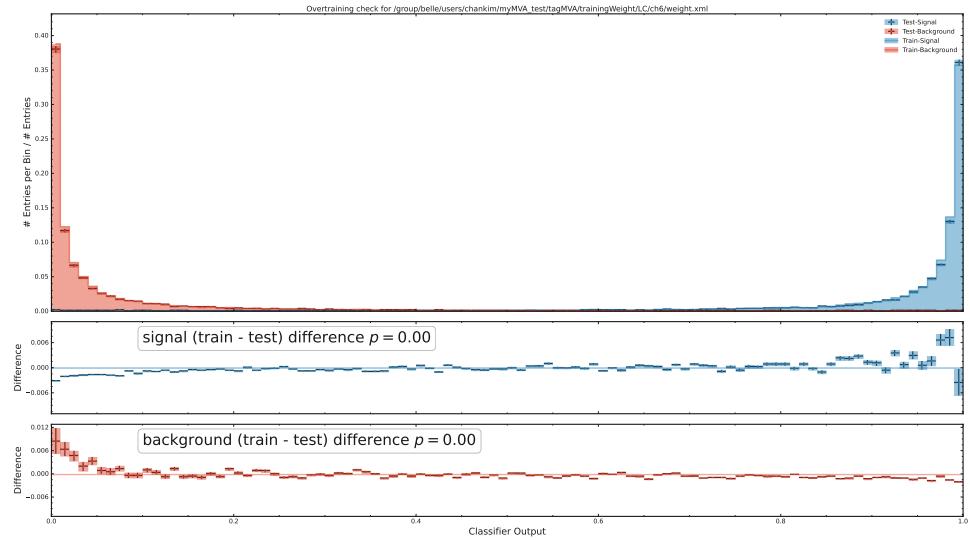


Figure 163: BDT output

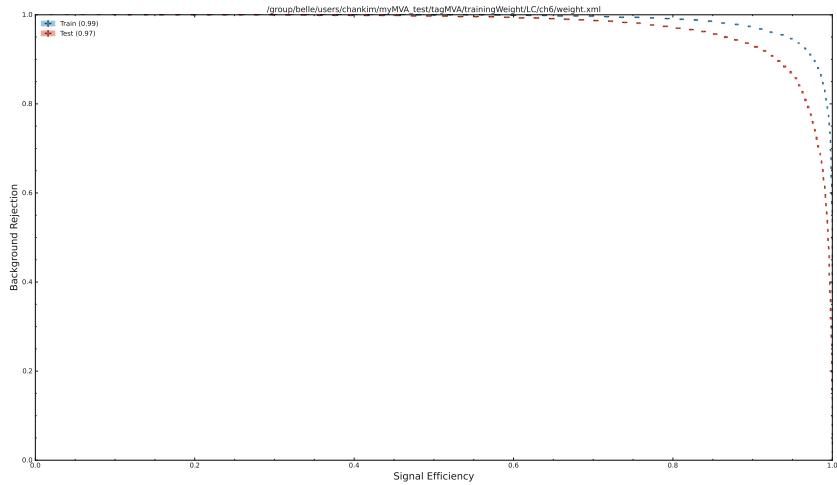


Figure 164: ROC Curve

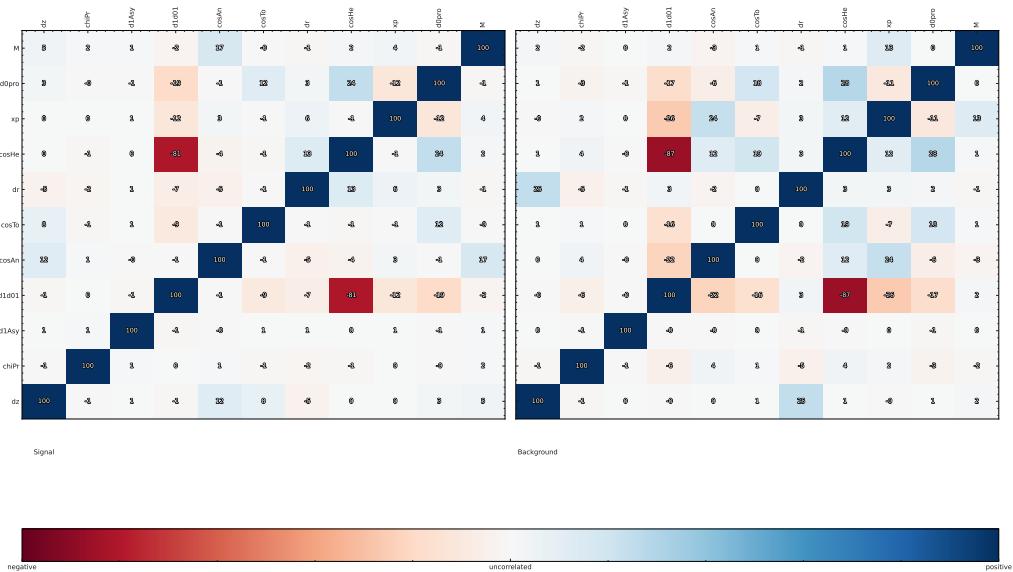


Figure 165: Correlation plot

421 A.1.44 $\Lambda_c^+ \rightarrow p^+ K_S^0 \pi^0$

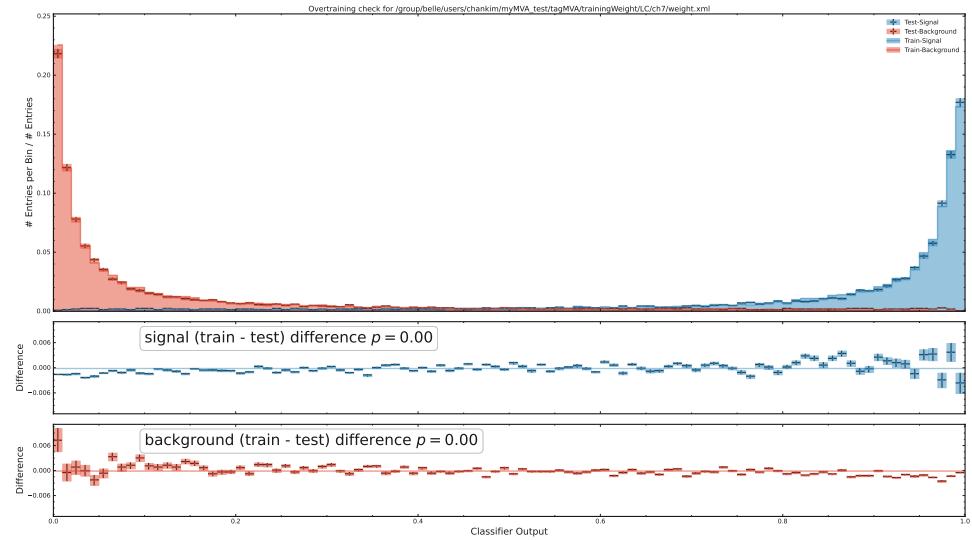


Figure 166: BDT output

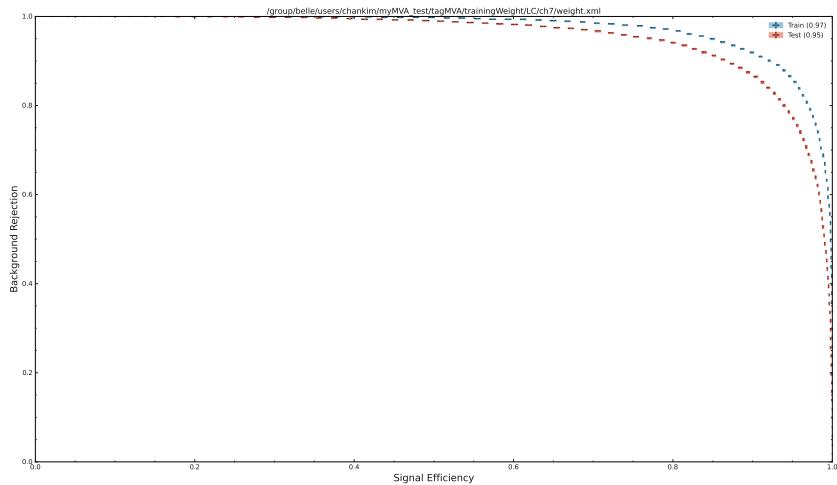


Figure 167: ROC Curve

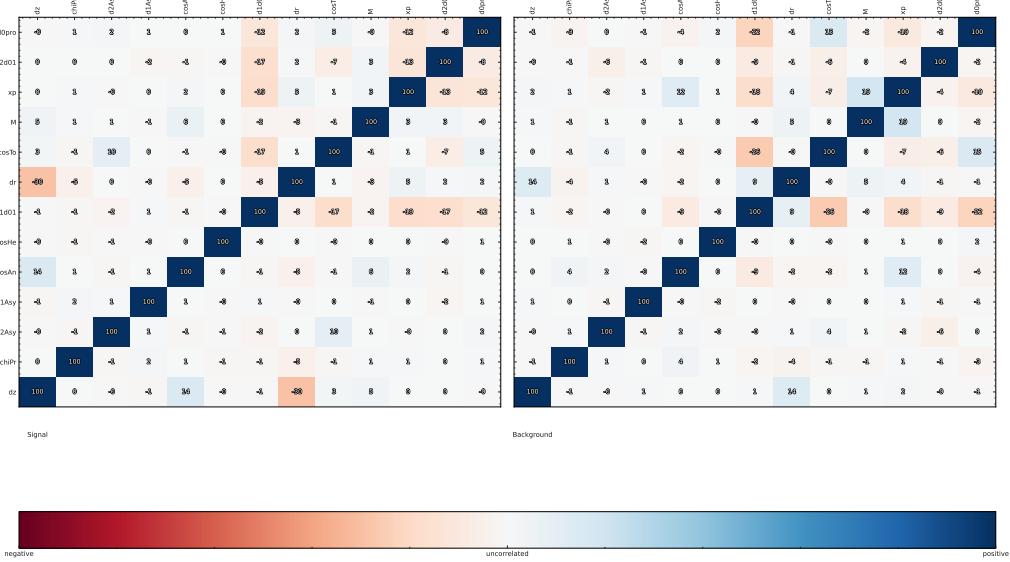


Figure 168: Correlation plot

422 A.1.45 $\Lambda_c^+ \rightarrow p^+ \pi^- \pi^+ K_S^0$

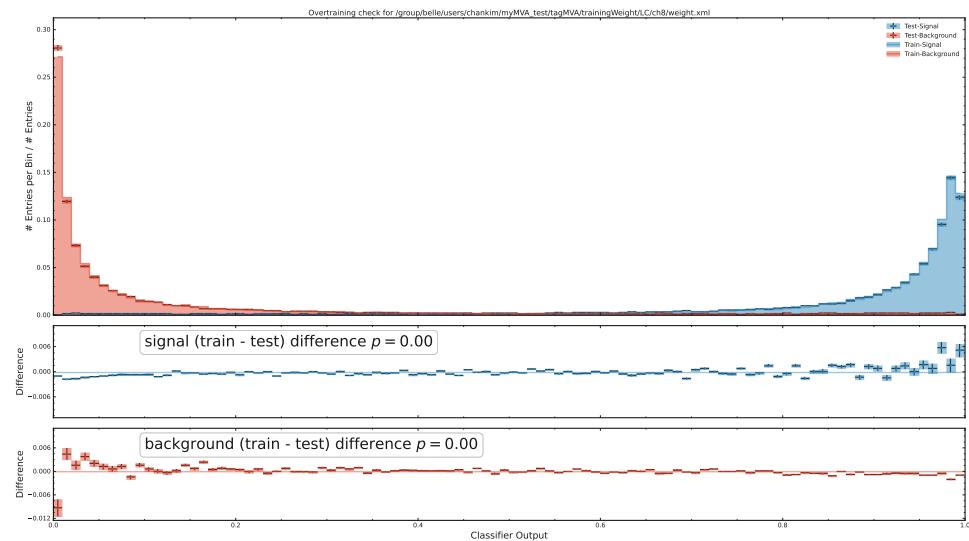


Figure 169: BDT output

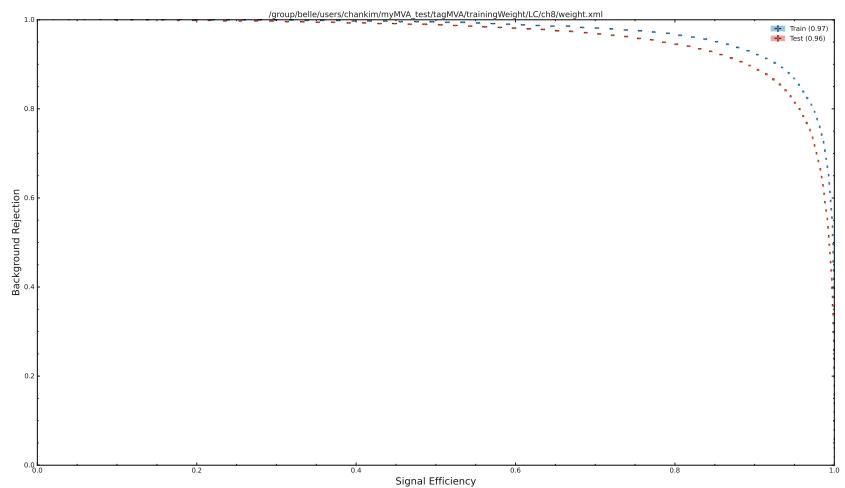


Figure 170: ROC Curve

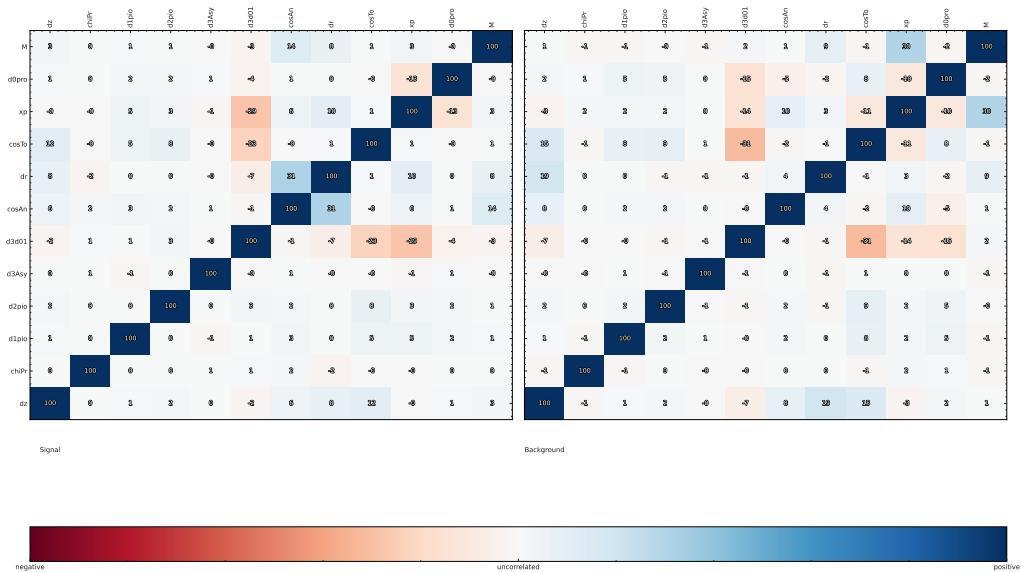


Figure 171: Correlation plot

423 A.1.46 $\Lambda_c^+ \rightarrow \pi^+ \Lambda^0$

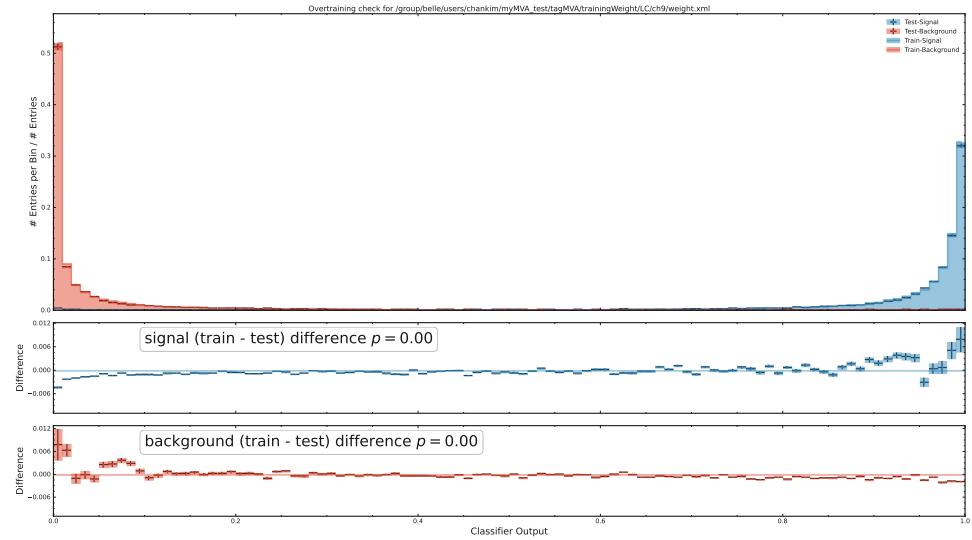


Figure 172: BDT output

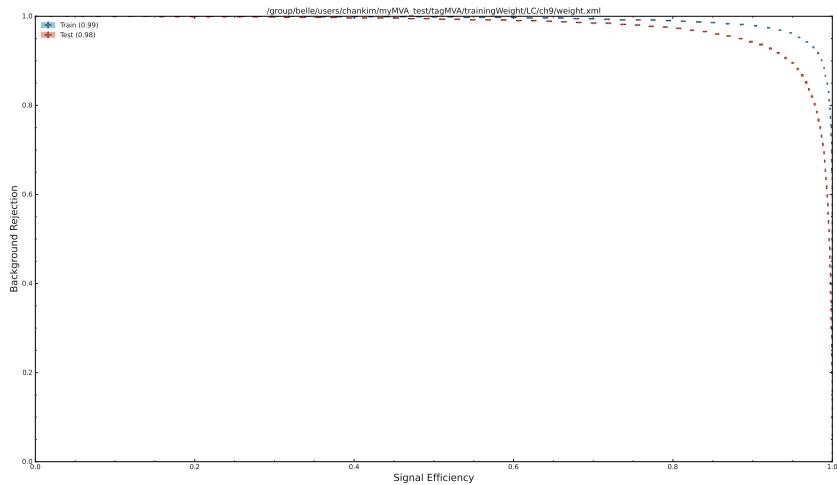


Figure 173: ROC Curve

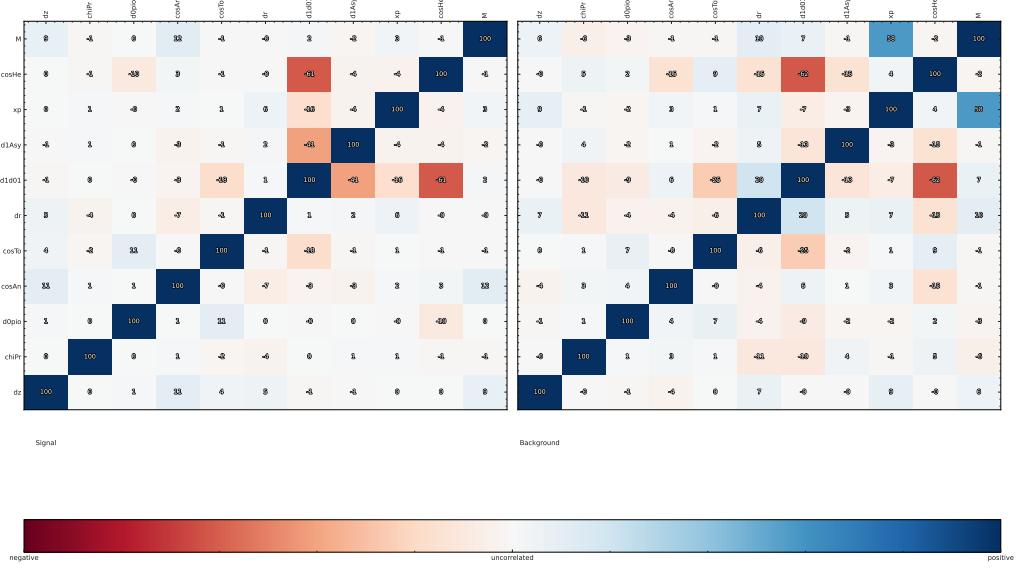


Figure 174: Correlation plot

424 A.1.47 $\Lambda_c^+ \rightarrow \pi^+ \pi^0 \Lambda^0$

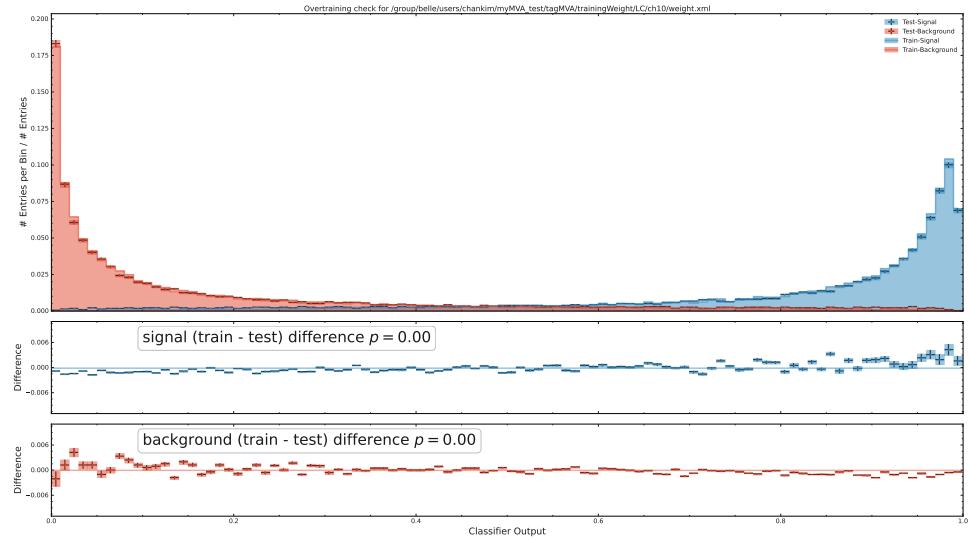


Figure 175: BDT output

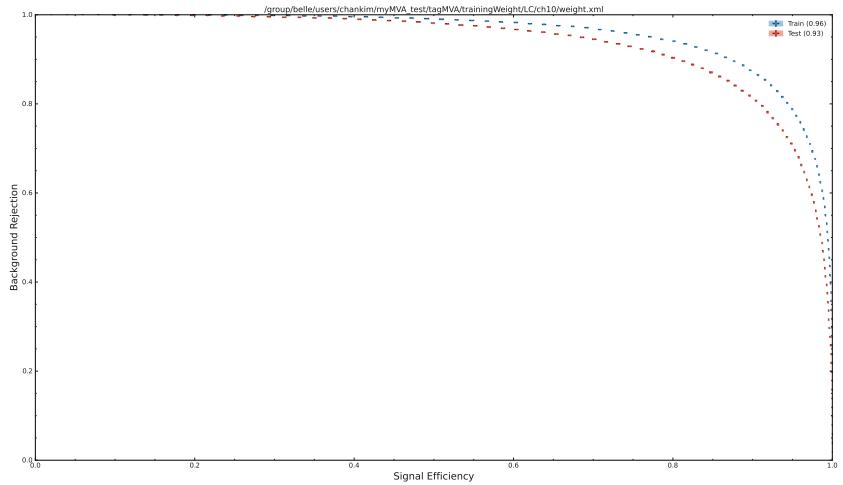
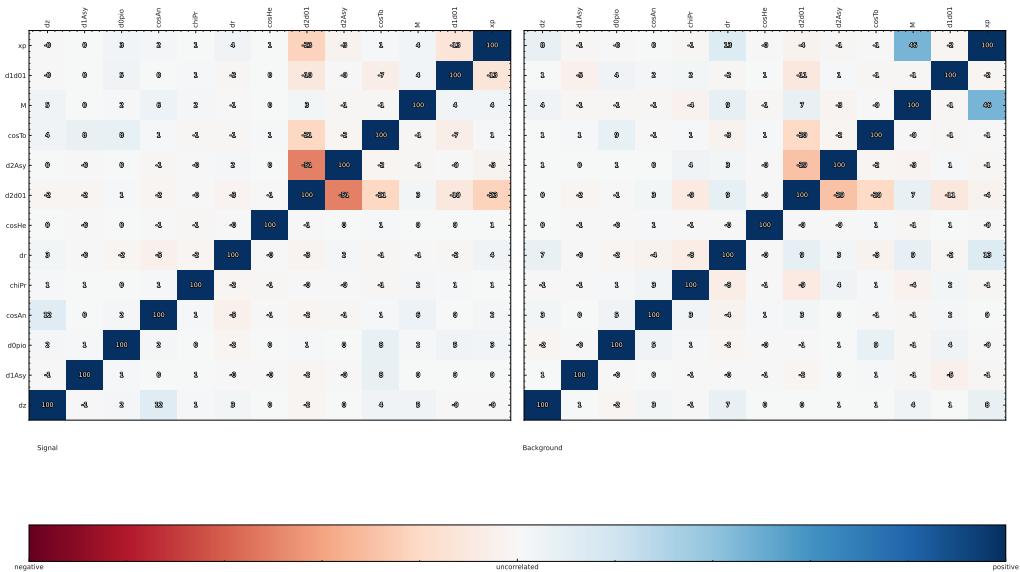


Figure 176: ROC Curve



425 A.1.48 $\Lambda_c^+ \rightarrow \pi^+ \pi^- \pi^+ \Lambda^0$

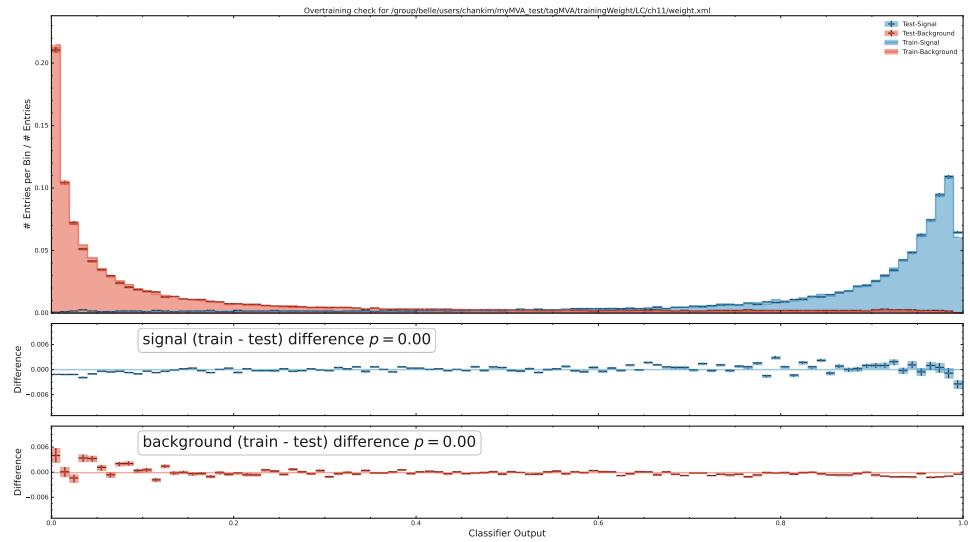


Figure 178: BDT output

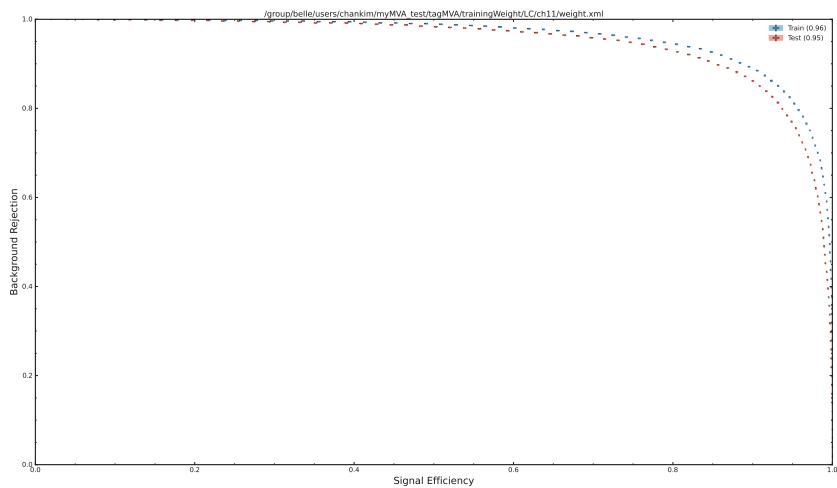


Figure 179: ROC Curve

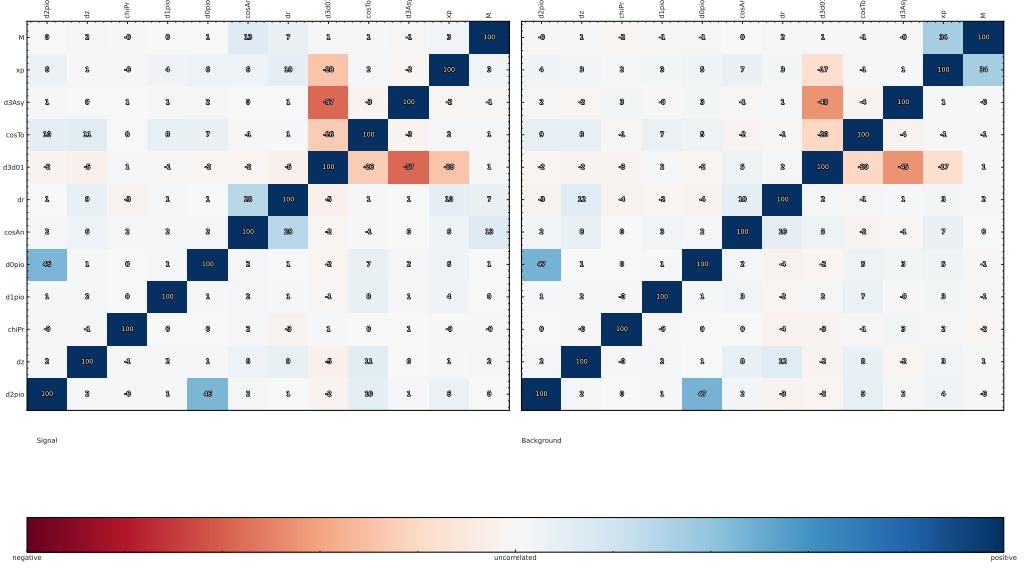


Figure 180: Correlation plot

426 A.1.49 $\Lambda_c^+ \rightarrow \pi^+ \pi^- \Sigma^+$

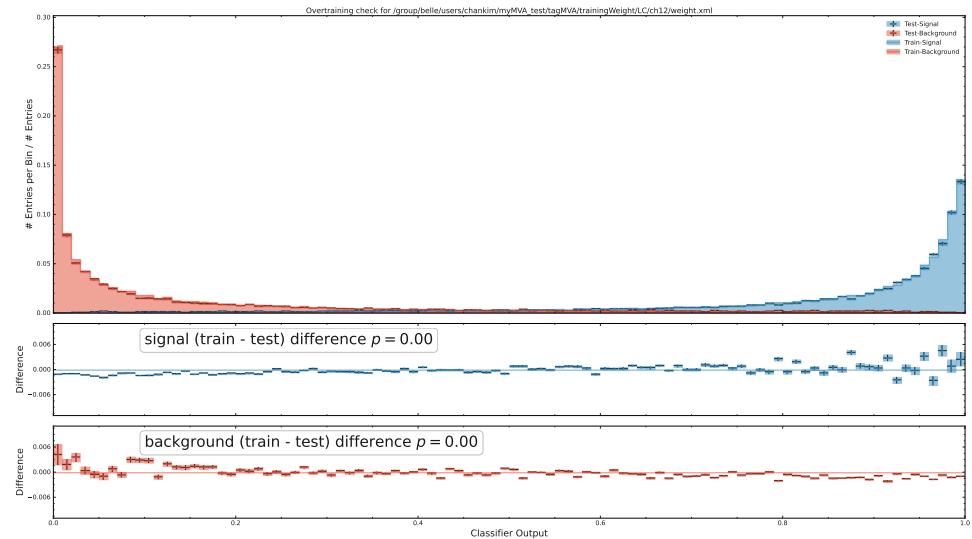


Figure 181: BDT output

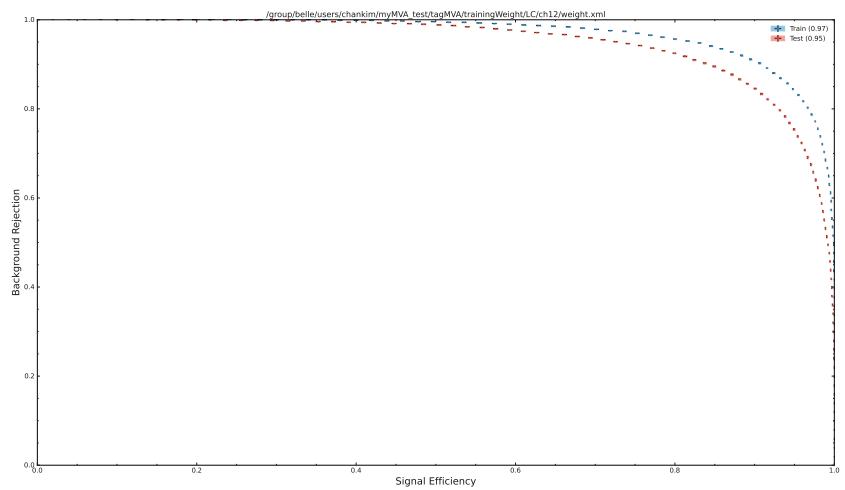


Figure 182: ROC Curve

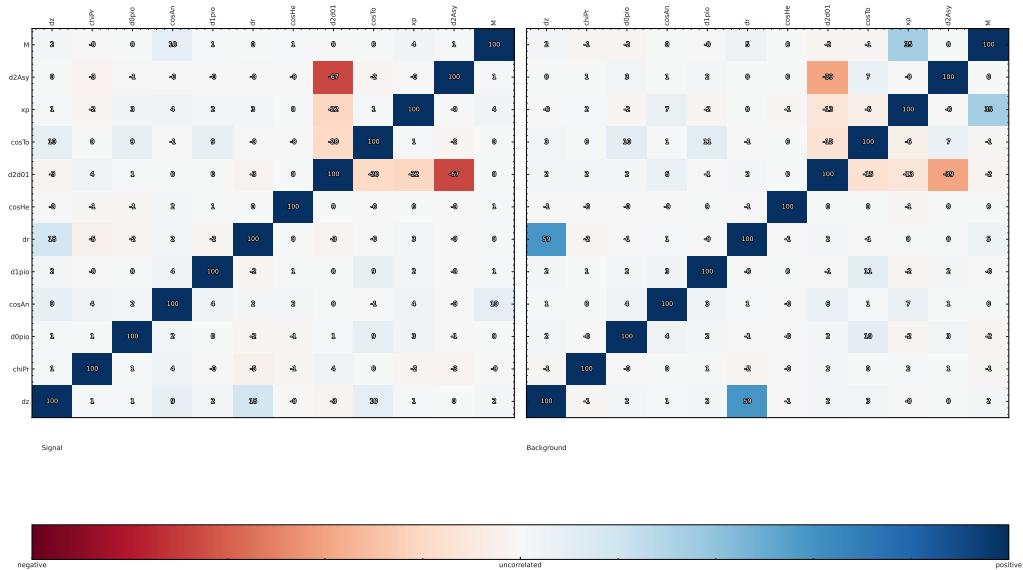


Figure 183: Correlation plot

427 A.1.50 $\Lambda_c^+ \rightarrow \pi^+ \pi^- \pi^0 \Sigma^+$

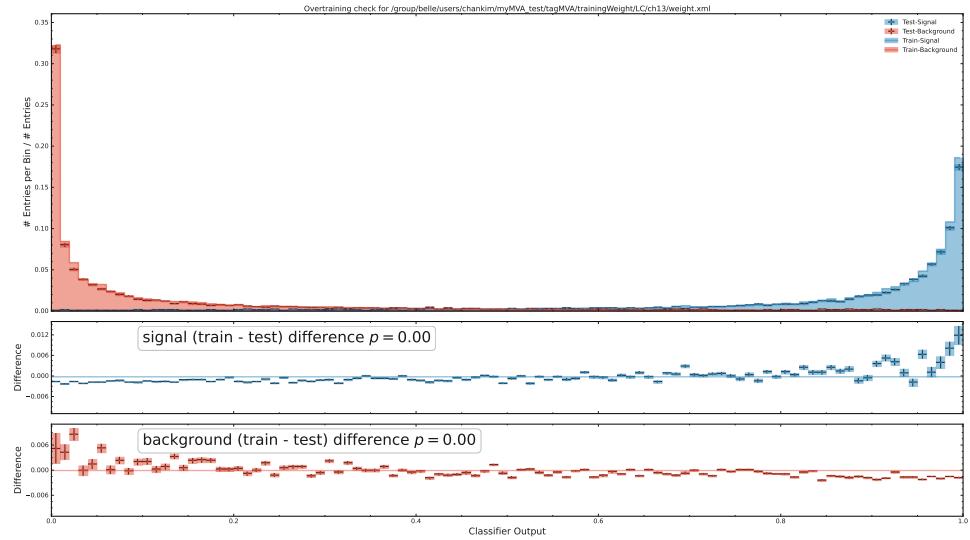


Figure 184: BDT output

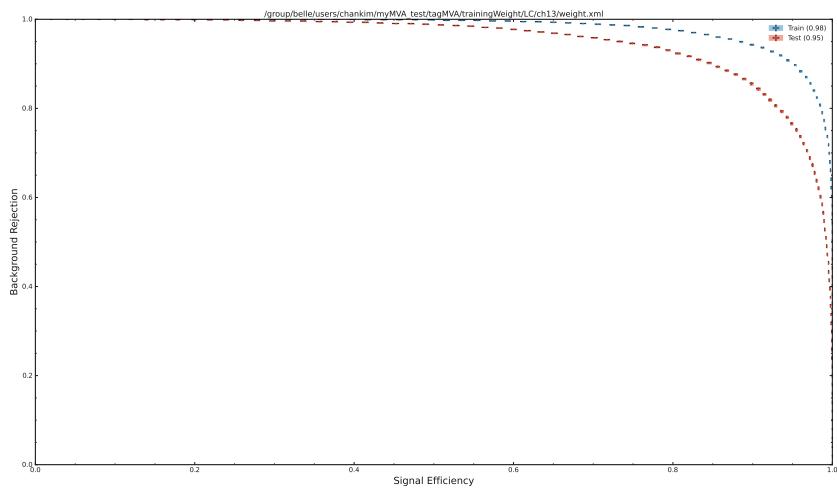


Figure 185: ROC Curve

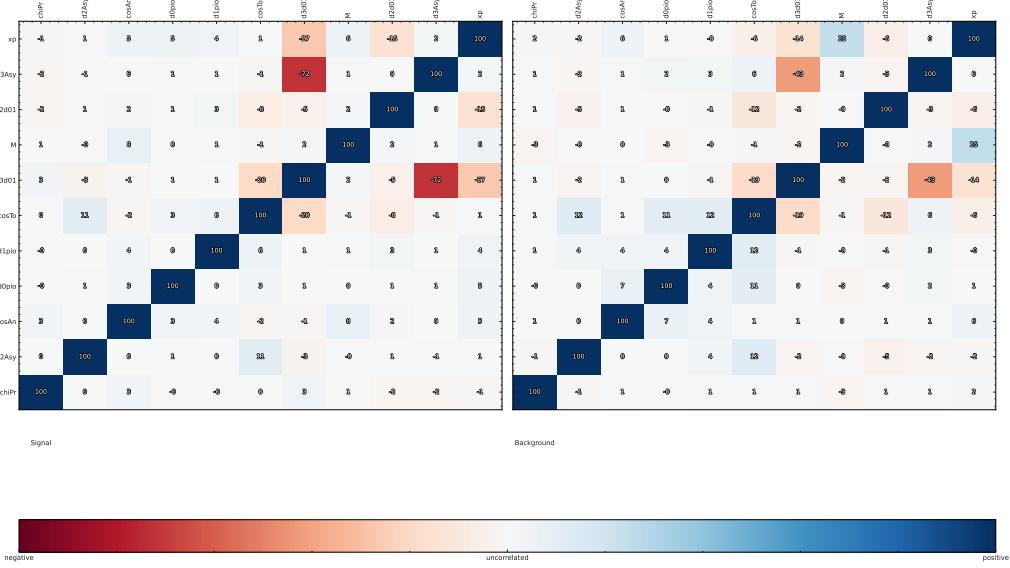


Figure 186: Correlation plot

428 A.1.51 $\Lambda_c^+ \rightarrow \pi^0 \Sigma^+$

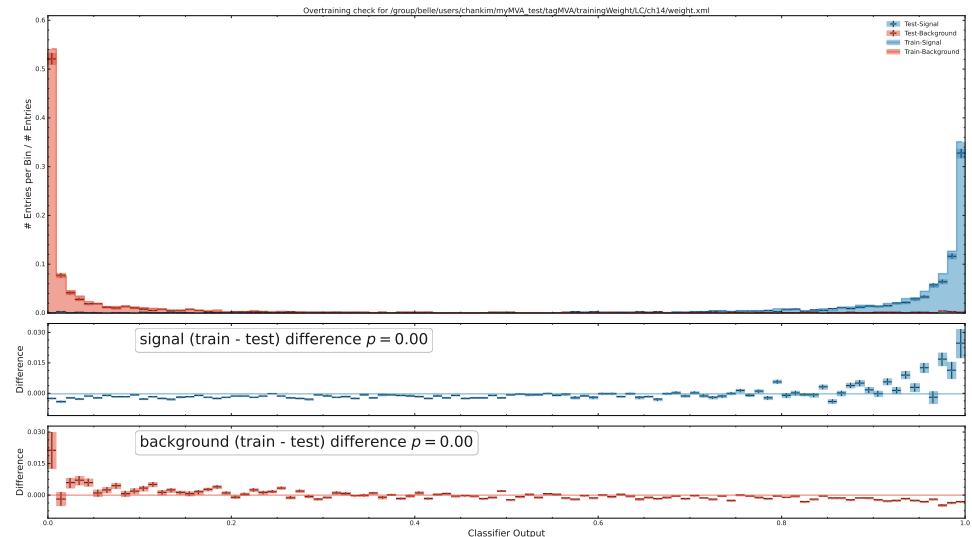


Figure 187: BDT output

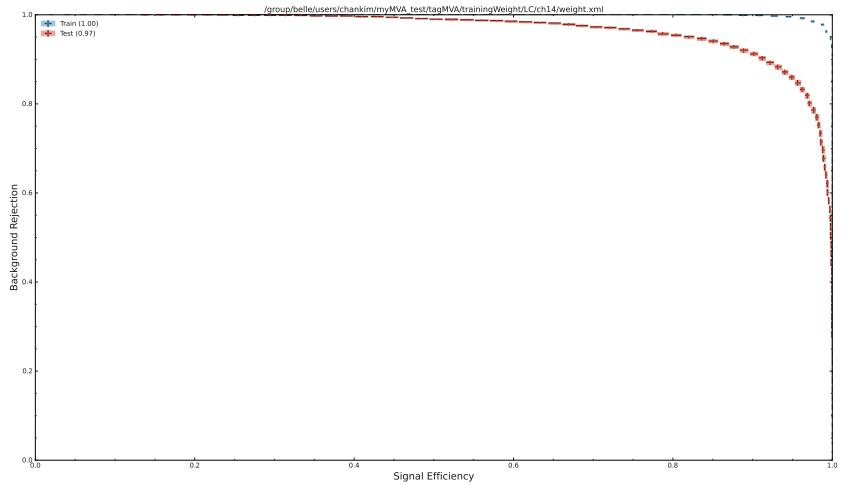


Figure 188: ROC Curve

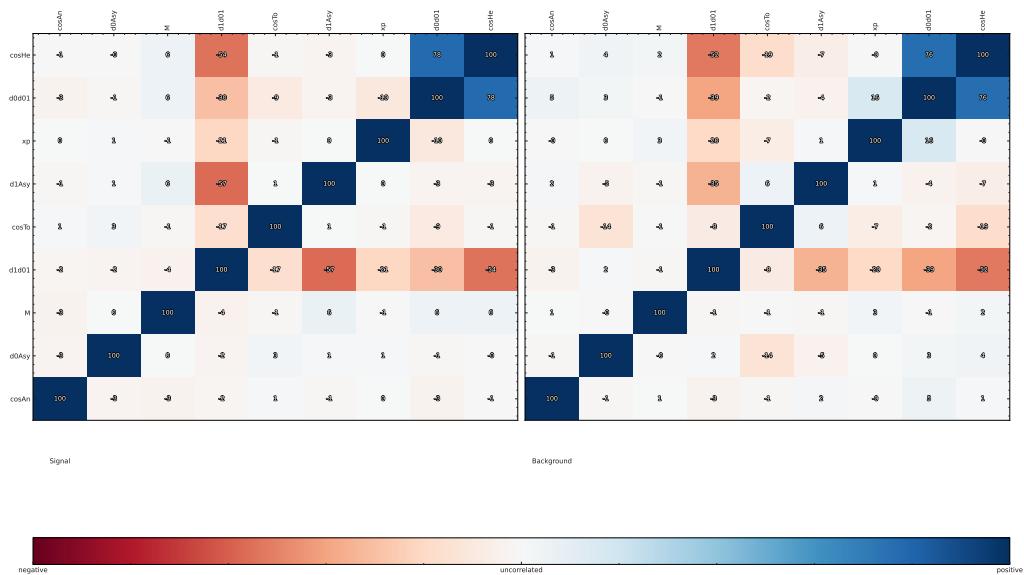


Figure 189: Correlation plot

429 A.1.52 $D^{*+} \rightarrow D^0\pi^+$

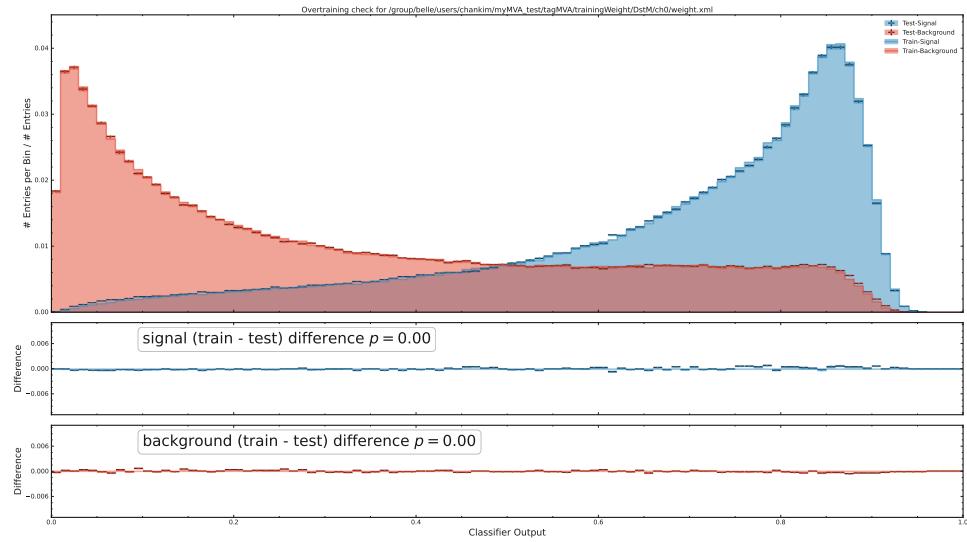


Figure 190: BDT output

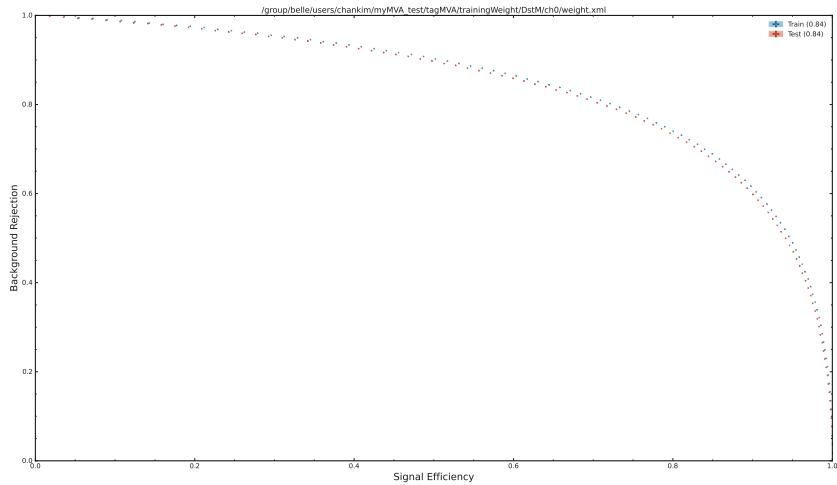


Figure 191: ROC Curve

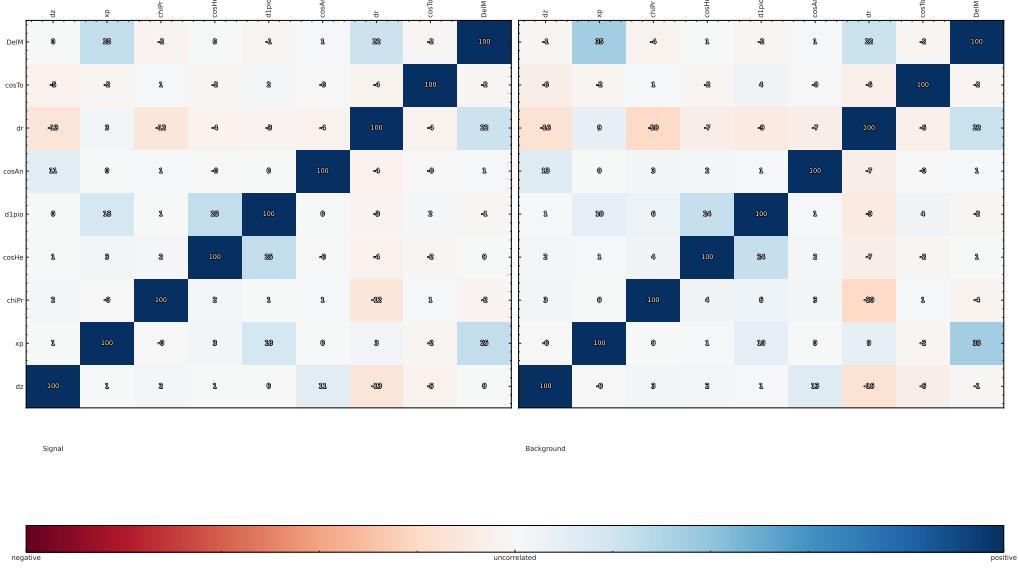


Figure 192: Correlation plot

430 A.1.53 $D^{*+} \rightarrow D^+ \pi^0$

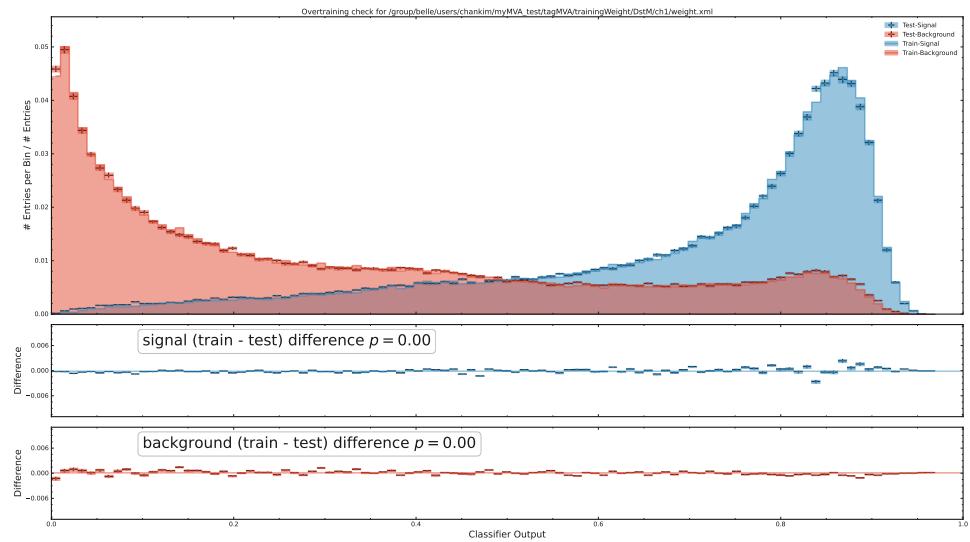


Figure 193: BDT output

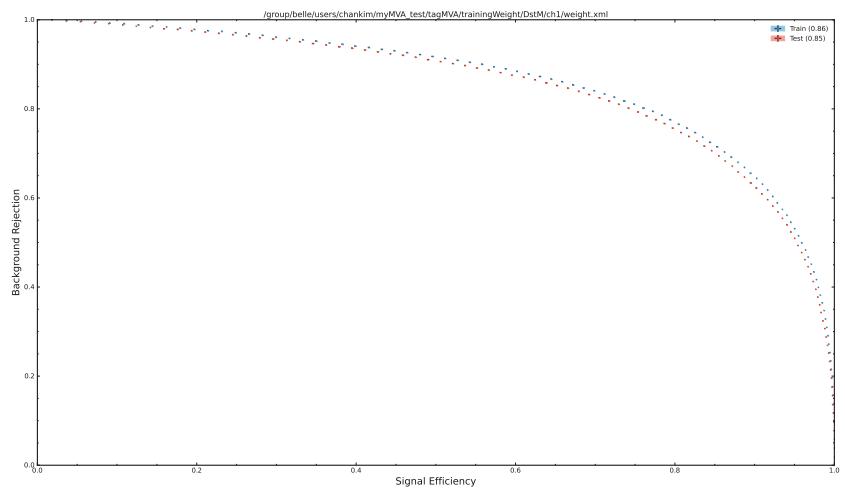


Figure 194: ROC Curve

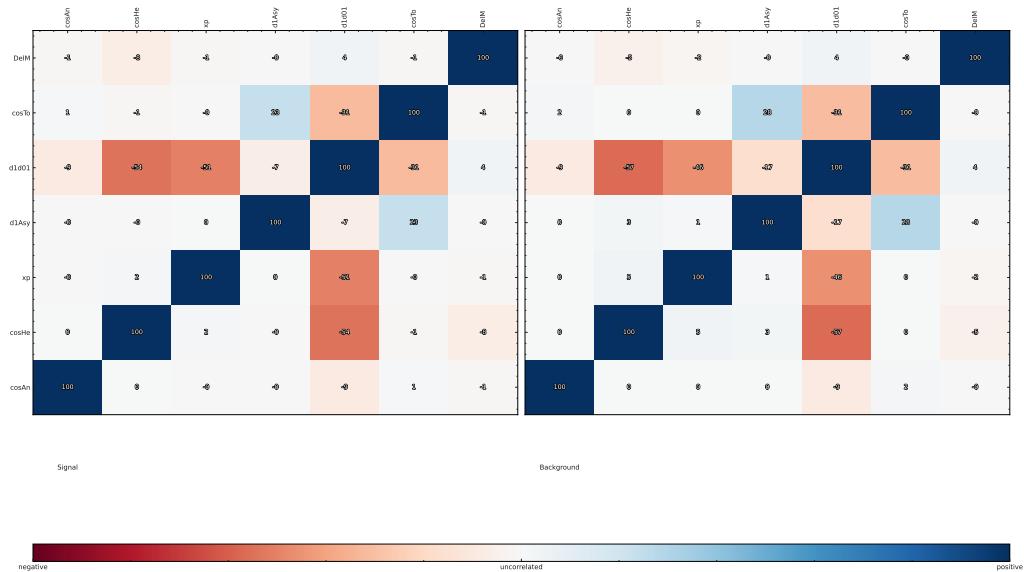


Figure 195: Correlation plot

431 A.1.54 $D^{*0} \rightarrow D^0\gamma$

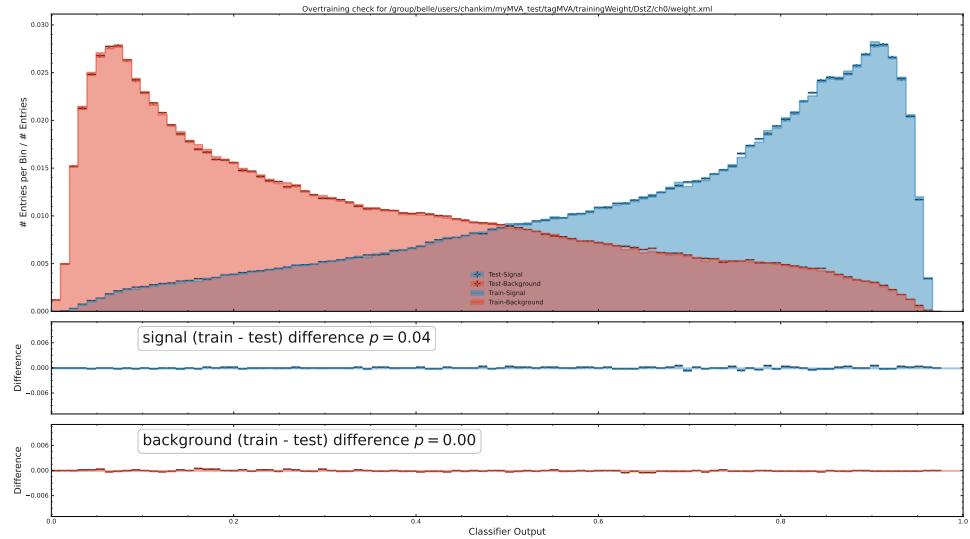


Figure 196: BDT output

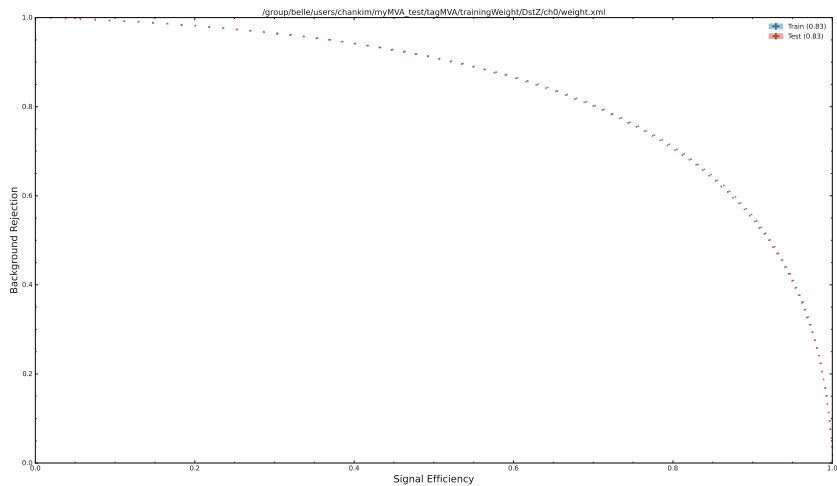


Figure 197: ROC Curve

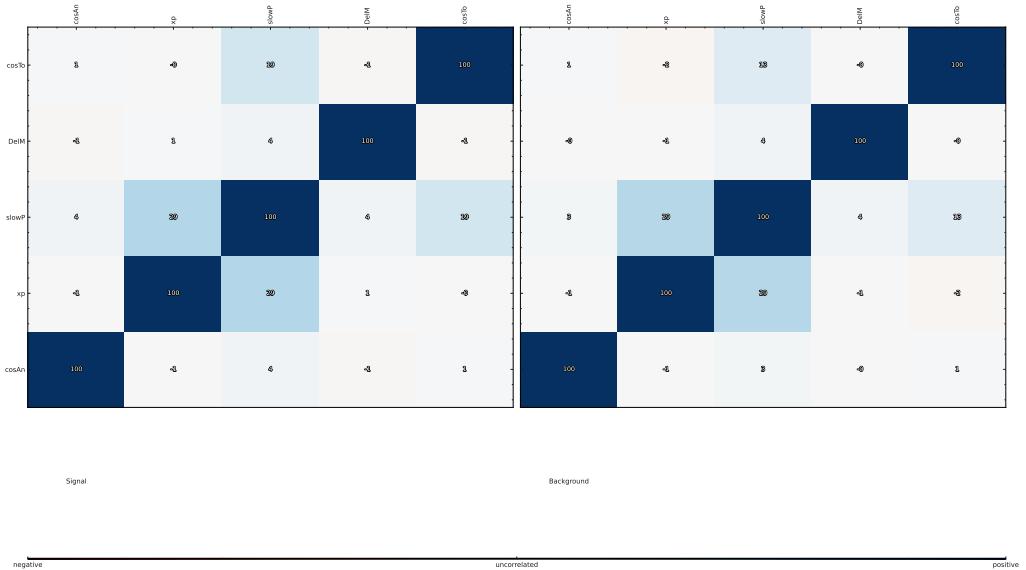


Figure 198: Correlation plot

432 A.1.55 $D^{*0} \rightarrow D^0\pi^0$

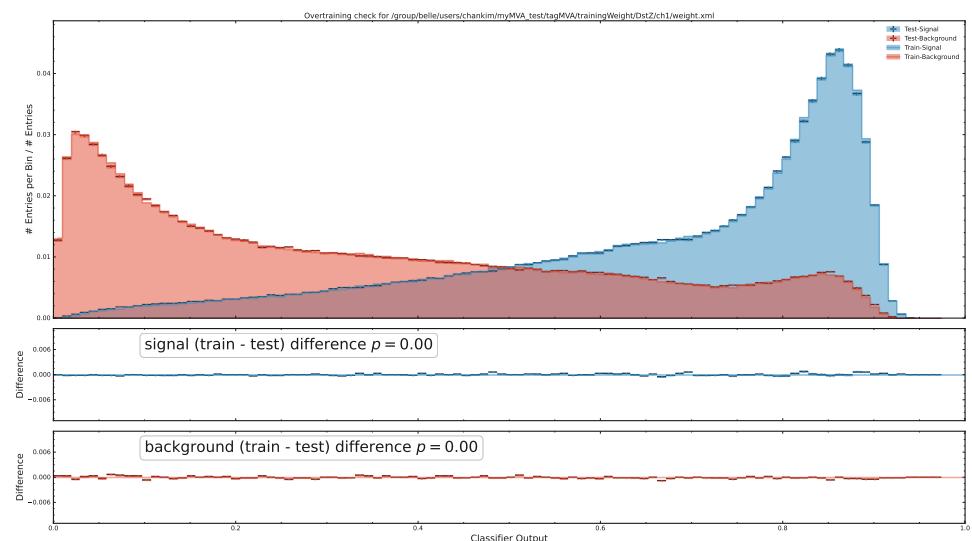


Figure 199: BDT output

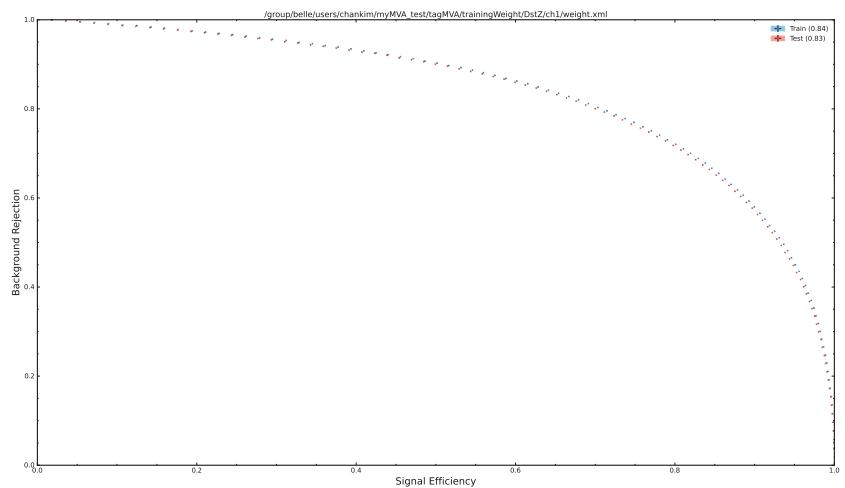


Figure 200: ROC Curve

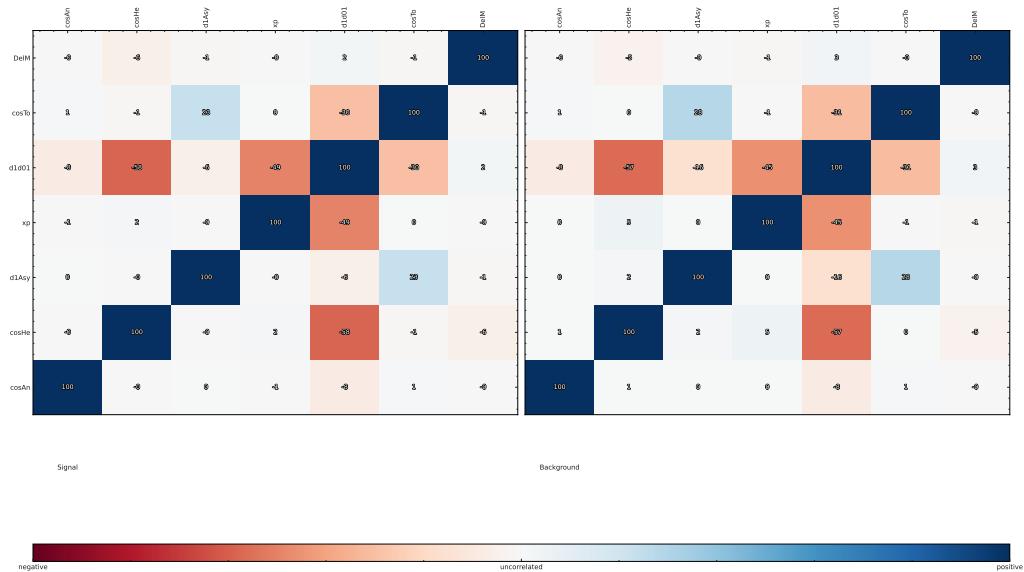


Figure 201: Correlation plot

433 A.1.56 $D_s^{*+} \rightarrow D_s^+ \gamma$

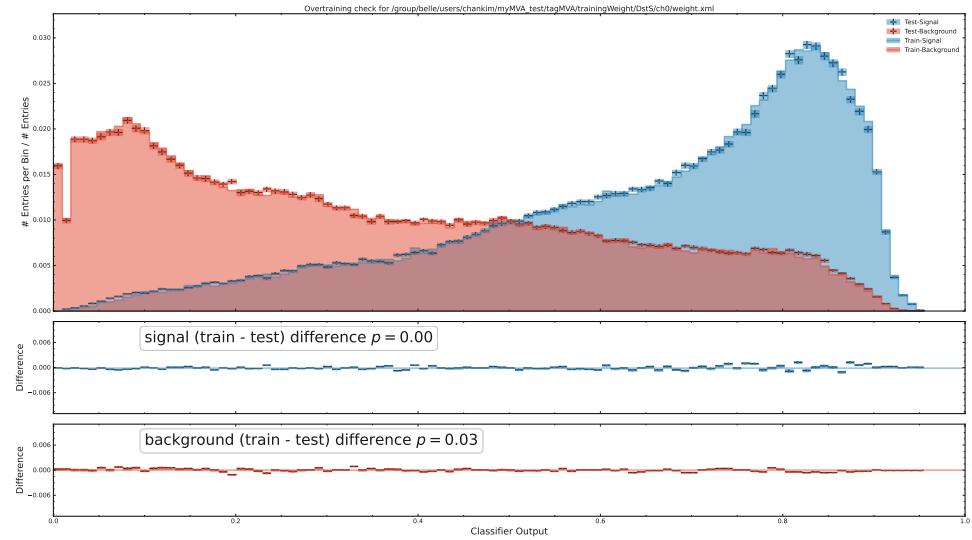


Figure 202: BDT output

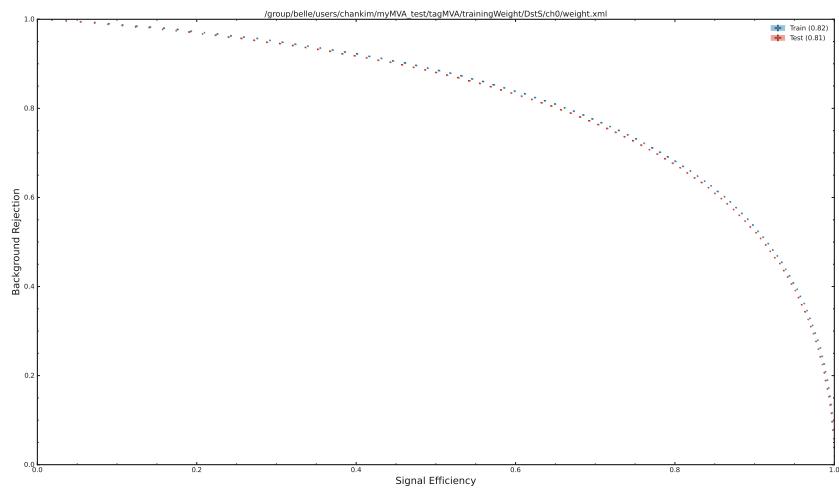


Figure 203: ROC Curve

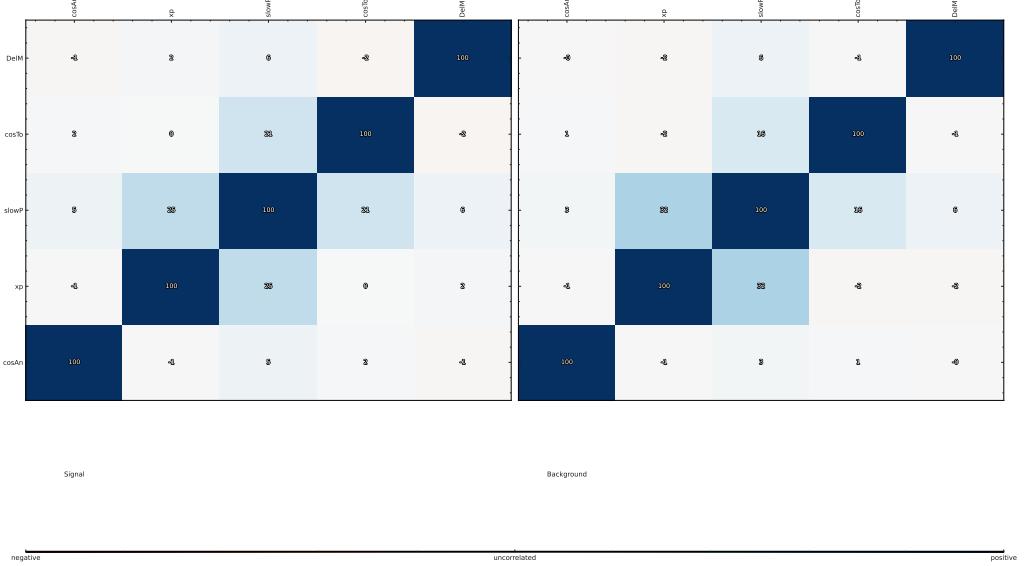


Figure 204: Correlation plot

434 B.0 Second Appendix

435 References

436 recommended references are

- 437 • Belle II physics: [1]
- 438 • B factories: [2]
- 439 • Belle: [3]
- 440 • CKM matrix: [4]
- 441 • Belle II detector: [5]
- 442 • SuperKEKB: [6]
- 443 • EVTGEN: [7]
- 444 • PYTHIA8: [8]
- 445 • KKMC: [9]
- 446 • TAUOLA: [10]
- 447 • PHOTOS: [11]
- 448 • GEANT4: [12]
- 449 • basf2: [13]

450 ● FEI: [14]

451 ● PDG: [15]

452 ● HFLAV: [16]

453 Some other standard references are available in `references.bib`. To add your own ref-
454 erences to the bibtex file use the command `./addrref` with the arXiv number or inspire
455 ID as argument. The added entries are might still need some editing:

456 ● check that Latex symbols in the titles are properly rendered (use Belle II symbols
457 whenever possible);

458 ● page ranges should in many cases be shortened to just having the start page;

459 ● collaborations might need to be added or indeed just the word “collaboration” put
460 after them;

461 ● for errata and/or addenda use the fields `extraPrefix`, `extraVolume`, `extraPages`,
462 `extraYear`, and `extraDoi`, as done for example in Ref. [1].

463 **References**

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⁴⁹⁸ Additional Material

⁴⁹⁹ This sections contains all figures and numbers that are requested to be approved for public
⁵⁰⁰ presentation.