$B_s^0 \to \mu^+\mu^-$ Cross Check Analysis

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Abstract

The aim of this analysis note is to provide supporting material for the cross check analysis for the search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ decays. It follows closely the documentation provided in [1] and includes direct comparison to the results in that note.

Contents

Official MC datasets
BsToMuMu_BsFilter_8TeV-pythia6-evtgen/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM
Data /MuOnia/Run2012A-13Jul2012-v1/AOD /MuOnia/Run2012A-recover-06Aug2012-v1/AOD /MuOnia/Run2012B-13Jul2012-v1/AOD /MuOnia/Run2012C-24Aug2012-v1/AOD /MuOnia/Run2012C-PromptReco-v2/AOD /MuOnia/Run2012C-EcalRecover_11Dec2012-v1/AOD /MuOnia/Run2012D-PromptReco-v1/AOD

1 Introduction

Goals and how the note is organized.

2 Datasets

The datasets used are shown in table **??**.

The events are selected using the same triggers as described in the reference [1].

The analysis is based on a boosted decision tree (BDT) algorithm to select $B_s^0 \to \mu^+\mu^-$ events from the background. A preselection is applied to the data and MC samples to reduce the size and remove outliers that might confuse the BDT training. The signal is taken from the $B_s^0 \to \mu^+\mu^-$ MC sample, while the background is taken from the sidebands in the data sample.
Despite the availability of the full 2012 dataset, in order to allow a direct comparison with the results in [1] this study is limited to runs <= 203002. The dataset is split in three different categories according the remainder of "event number%3".

3 Selection

3.1 pre-selection

The same preselection as in [1] is used.

3.2 muon identification

The muons are chosen to pass global muon prompt tight selection (GM_PT). [to be updated]

3.3 variable distributions

The distributions of the variables used for the BDT training are shown in Figures 1 and 2.

3.4 variable ranking and correlations

Tables **??** and **??** show the ranking of variables before the BDT training.

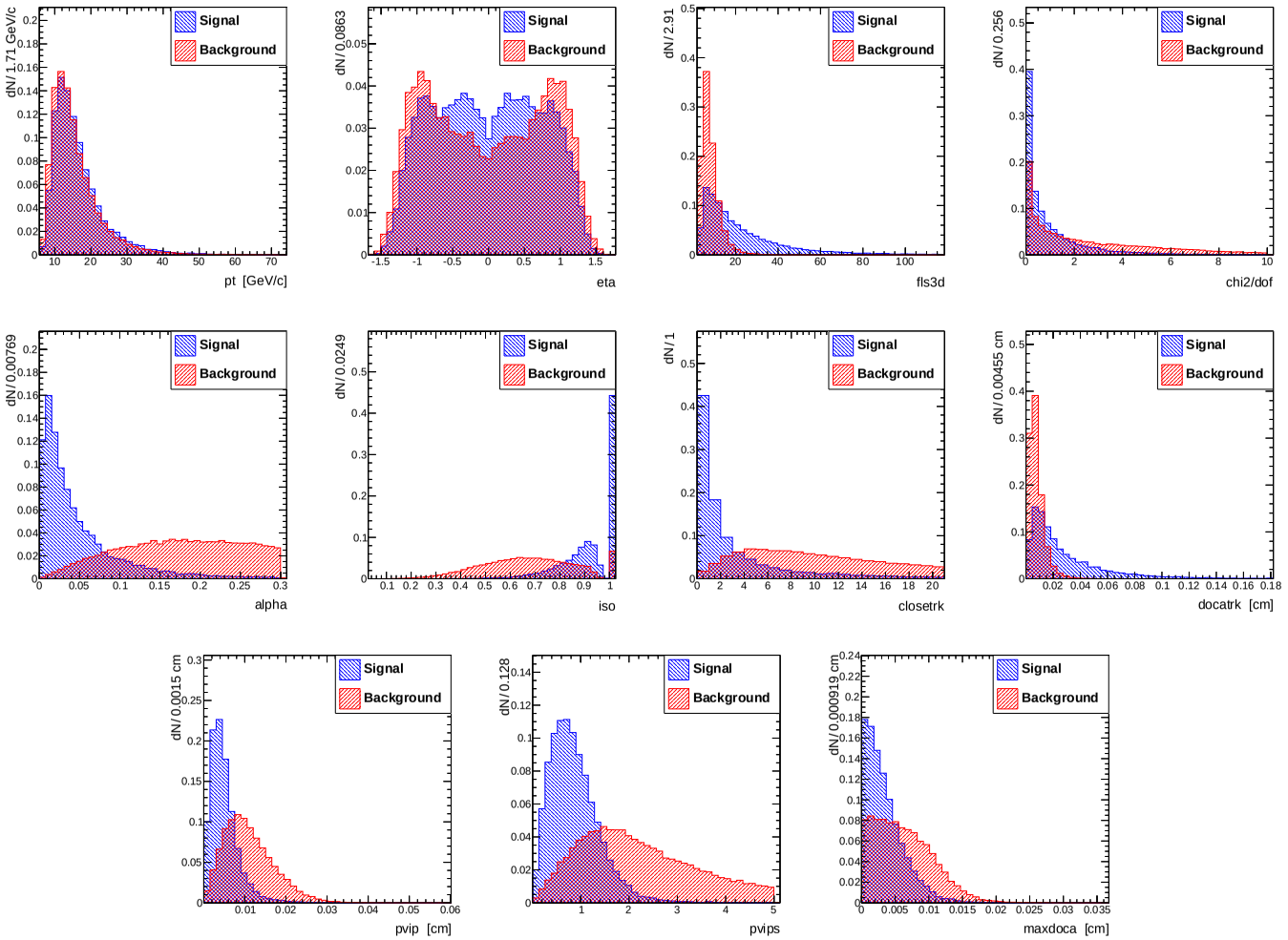

Figure 1: Standard TMVA plot of the input variables for the barrel BDT for signal (blue) and background (red). The background is extracted from data dimuon sidebands.

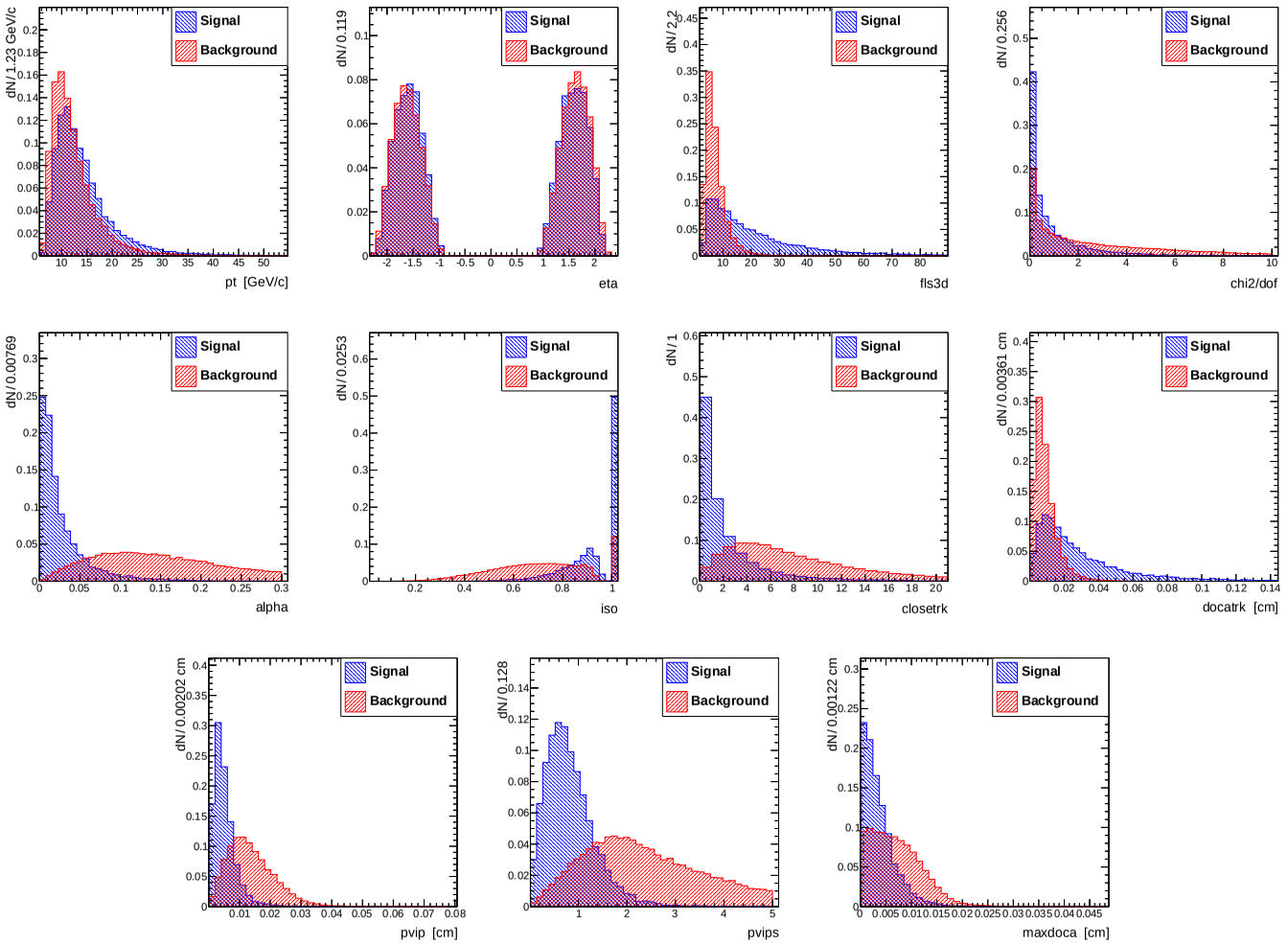

Figure 2: Standard TMVA plot of the input variables for the endcaps BDT for signal (blue) and background (red). The background is extracted from data dimuon sidebands.

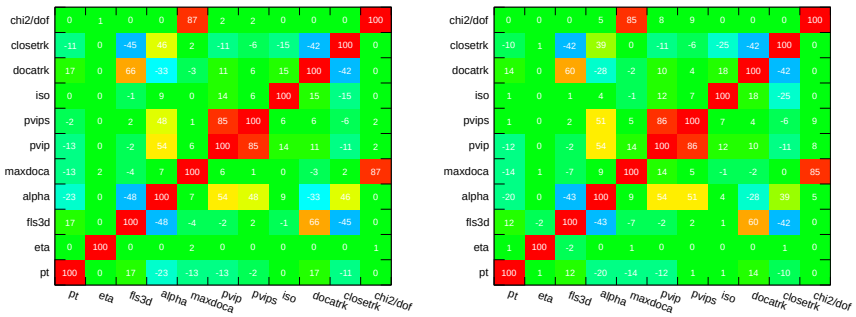

Figure 3: Correlation matrix for signal events in the barrel (left) and the endcap (right).

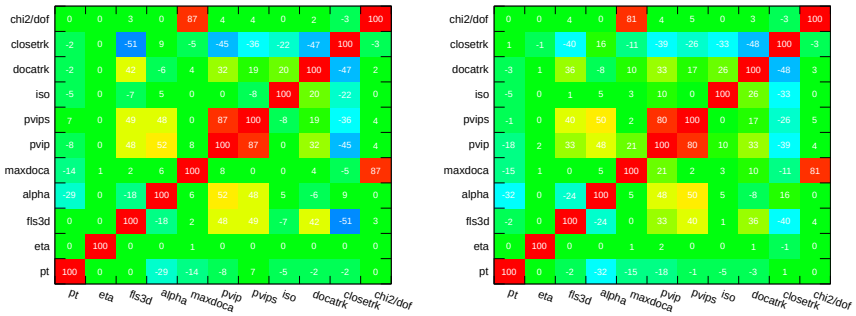

Figure 4: Correlation matrix for background events in the barrel (left) and the endcap (right).

	0		1		2	
rank	variable	separation	variable	separation	variable	separation
1	alpha	5.430e-01	alpha	5.376e-01	alpha	5.481e-01
2	iso	4.392e-01	iso	4.452e-01	iso	4.403e-01
3	closetrk	4.338e-01	closetrk	4.298e-01	closetrk	4.230e-01
4	pvips	4.035e-01	pvips	3.986e-01	pvips	4.028e-01
5	pvip	3.269e-01	docatrk	3.228e-01	pvip	3.317e-01
6	docatrk	3.263e-01	pvip	3.185e-01	docatrk	3.222e-01
7	fls3d	3.086e-01	fls3d	3.087e-01	fls3d	3.107e-01
8	maxdoca	1.388e-01	maxdoca	1.391e-01	maxdoca	1.422e-01
9	chi2/dof	1.338e-01	chi2/dof	1.346e-01	chi2/dof	1.397e-01
10	eta	1.950e-02	eta	1.890e-02	eta	1.961e-02
11	pt	6.670e-03	pt	6.854e-03	pt	7.072e-03

Table 1: Variable ranking for events of the three different event samples in the barrel before BDT training.

	0		1		2	
rank	variable	separation	variable	separation	variable	separation
1	alpha	6.258e-01	alpha	6.237e-01	alpha	6.288e-01
2	pvips	4.817e-01	pvips	4.792e-01	pvips	4.864e-01
3	pvip	4.290e-01	pvip	4.215e-01	pvip	4.290e-01
4	closetrk	3.962e-01	closetrk	3.985e-01	closetrk	4.049e-01
5	iso	3.585e-01	iso	3.585e-01	iso	3.627e-01
6	fls3d	3.437e-01	fls3d	3.518e-01	fls3d	3.527e-01
7	docatrk	2.962e-01	docatrk	2.938e-01	docatrk	3.034e-01
8	maxdoca	1.638e-01	maxdoca	1.665e-01	maxdoca	1.679e-01
9	chi2/dof	1.471e-01	chi2/dof	1.489e-01	chi2/dof	1.504e-01
10	pt	3.738e-02	pt	4.021e-02	pt	3.811e-02
11	eta	4.318e-03	eta	4.264e-03	eta	3.595e-03

Table 2: Variable ranking for events of the three different event samples in the endcaps before BDT training.

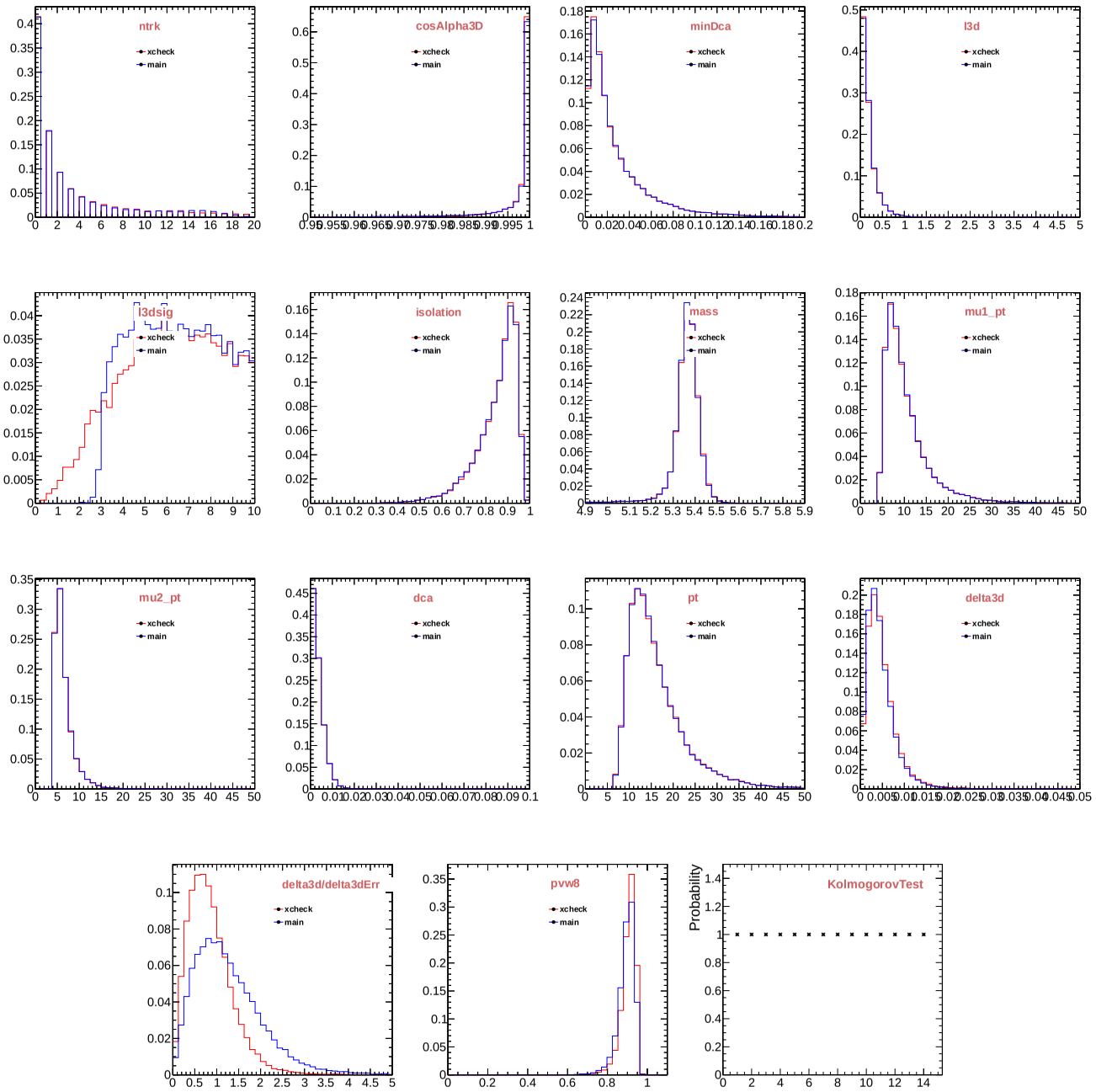

Figure 5: Variable comparisons between the main analysis and the cross-check analysis. Part I: MC barrel.

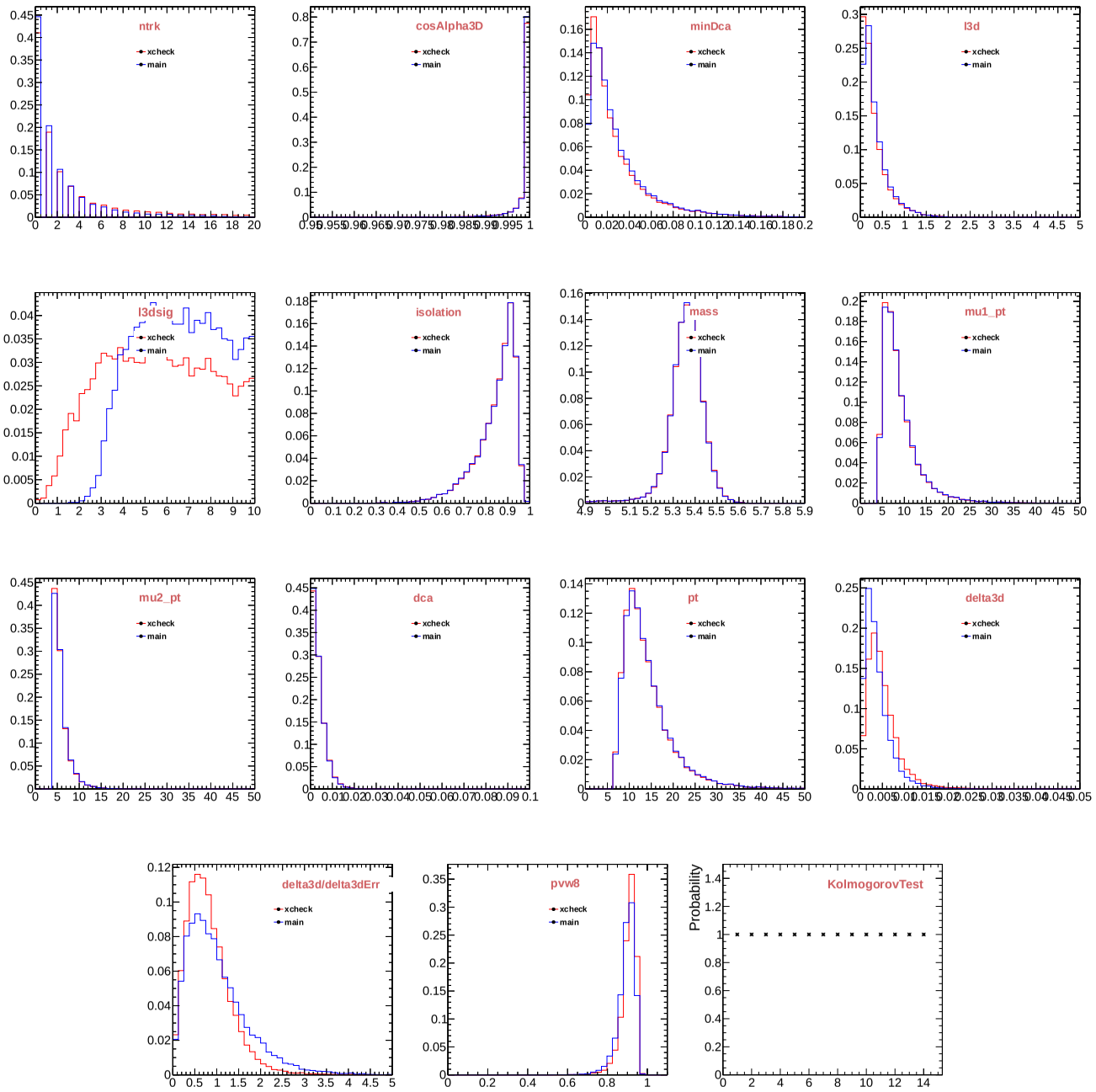

Figure 6: Variable comparisons between the main analysis and the cross-check analysis. Part I: MC endcaps.

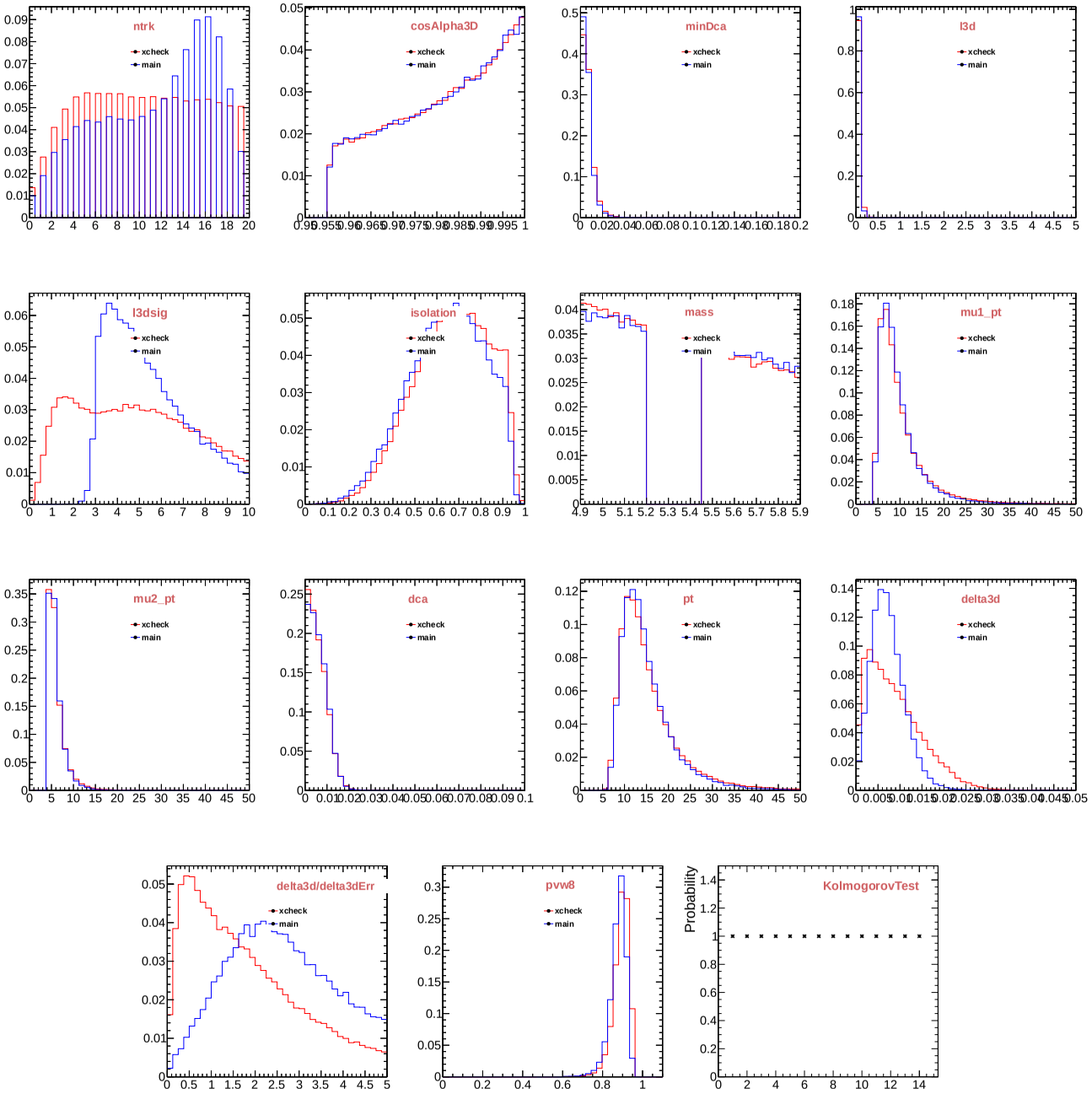

Figure 7: Variable comparisons between the main analysis and the cross-check analysis. Part I: Data barrel.

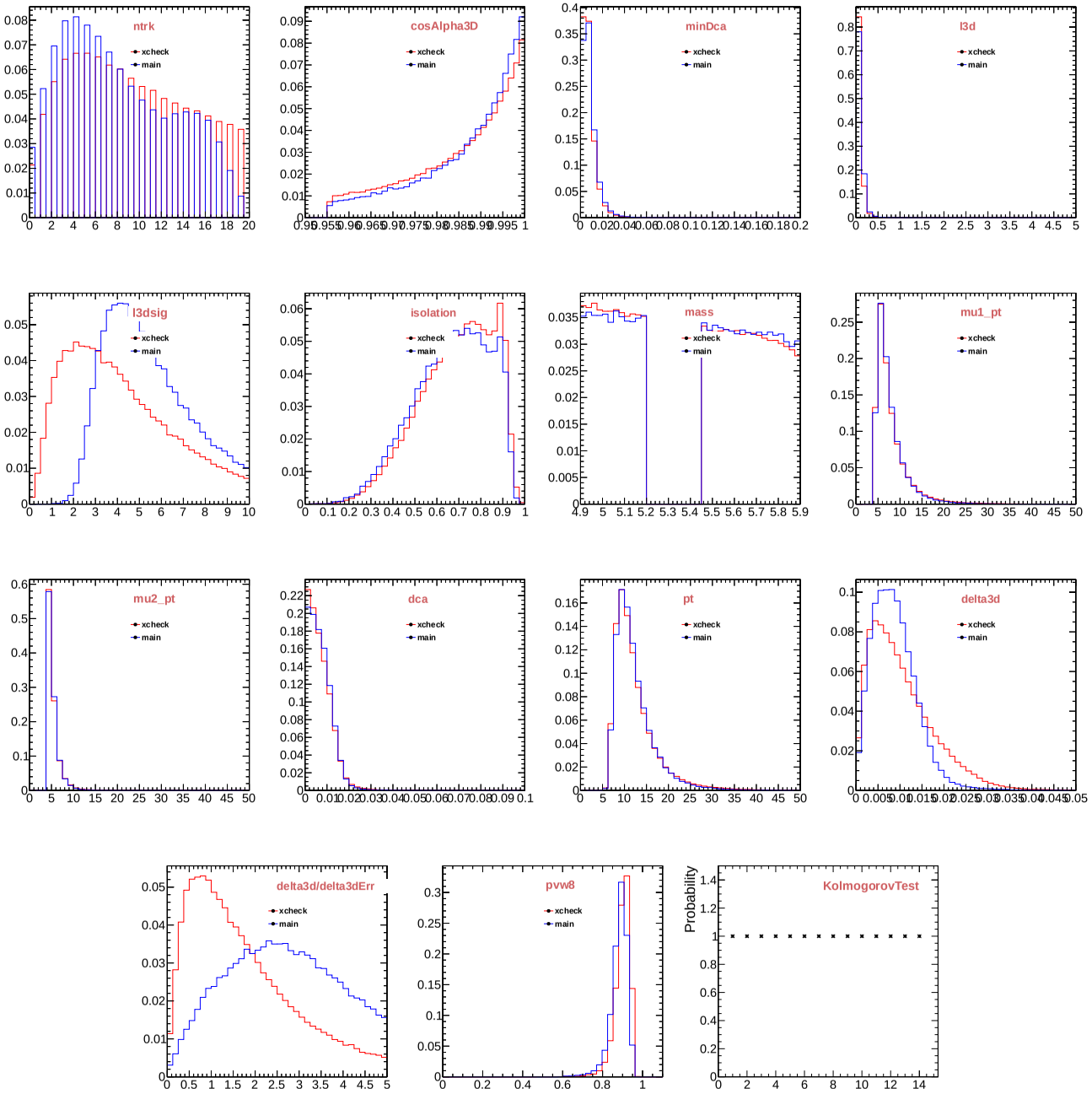

Figure 8: Variable comparisons between the main analysis and the cross-check analysis. Part I: Data endcaps.

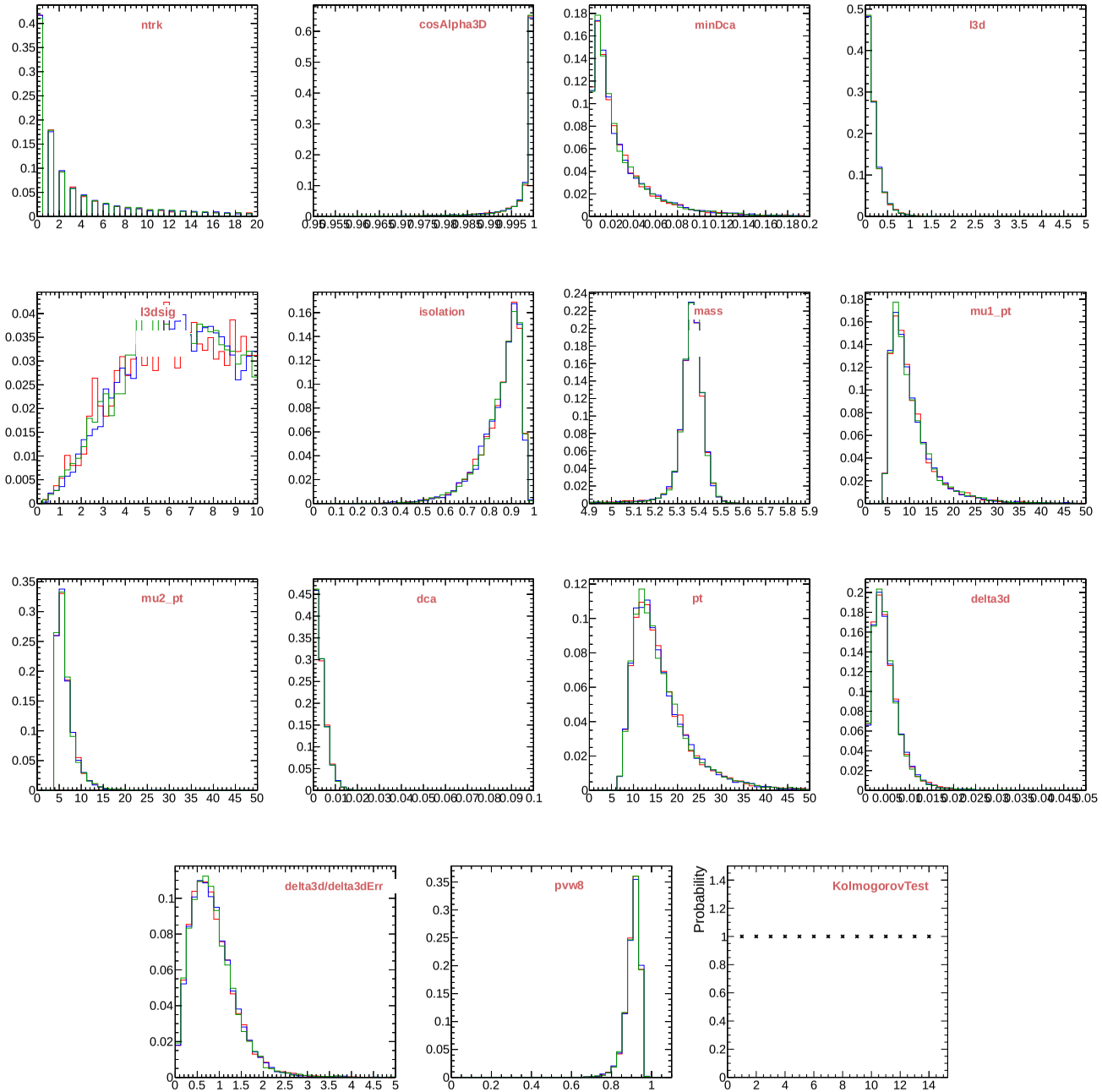

Figure 9: Overlay of BDT training variable distributions in Signal MC for events of the three subsets in the barrel. The plot on the bottom right summarizes all KS probablities.

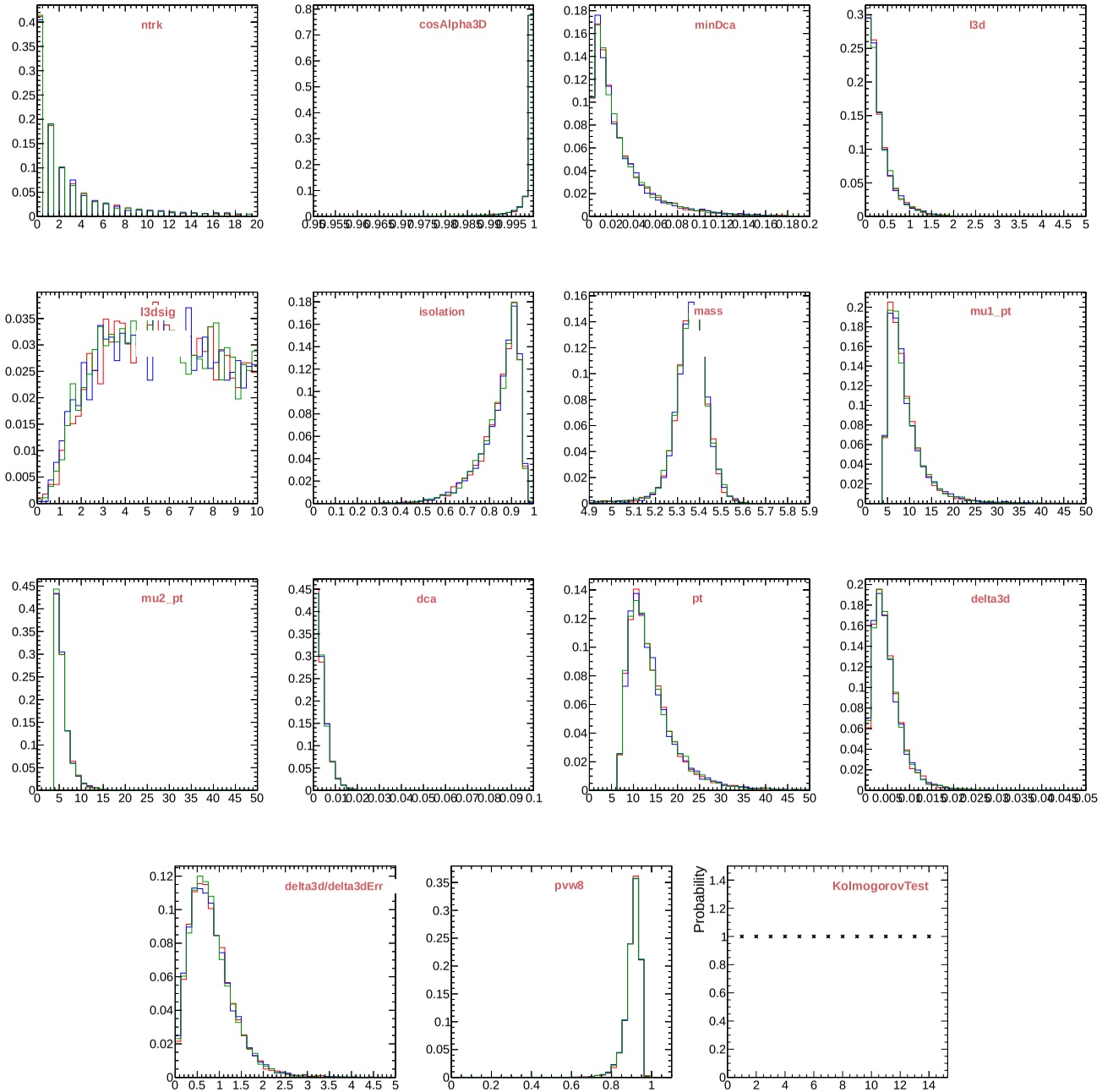

Figure 10: Overlay of BDT training variable distributions in Signal MC for events of the three subsets in the endcap. The plot on the bottom right summarizes all KS probablities.

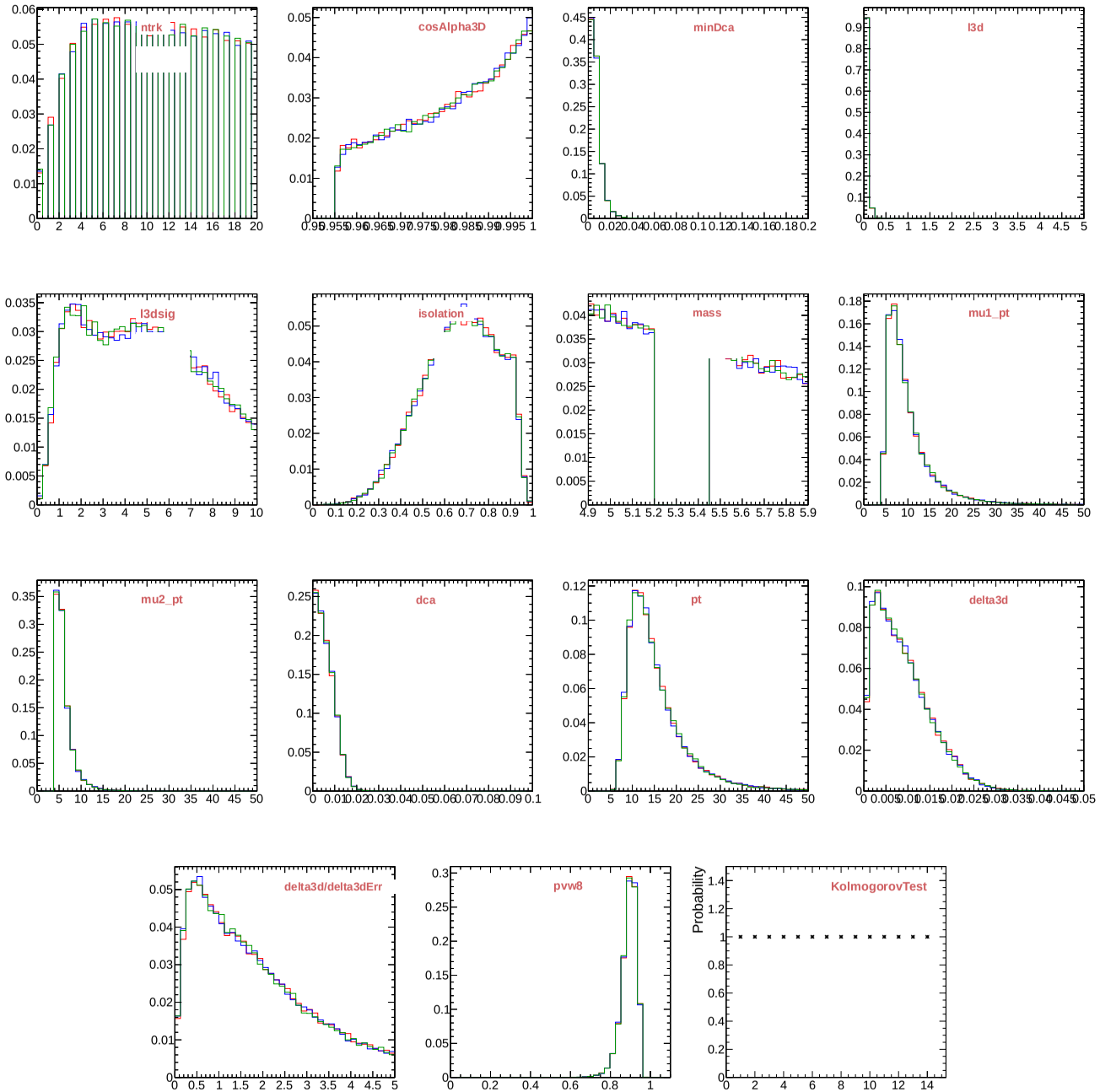

Figure 11: Overlay of BDT training variable distributions in data sideband background for events of the three subsets in the barrel. The plot on the bottom right summarizes all KS probablities.

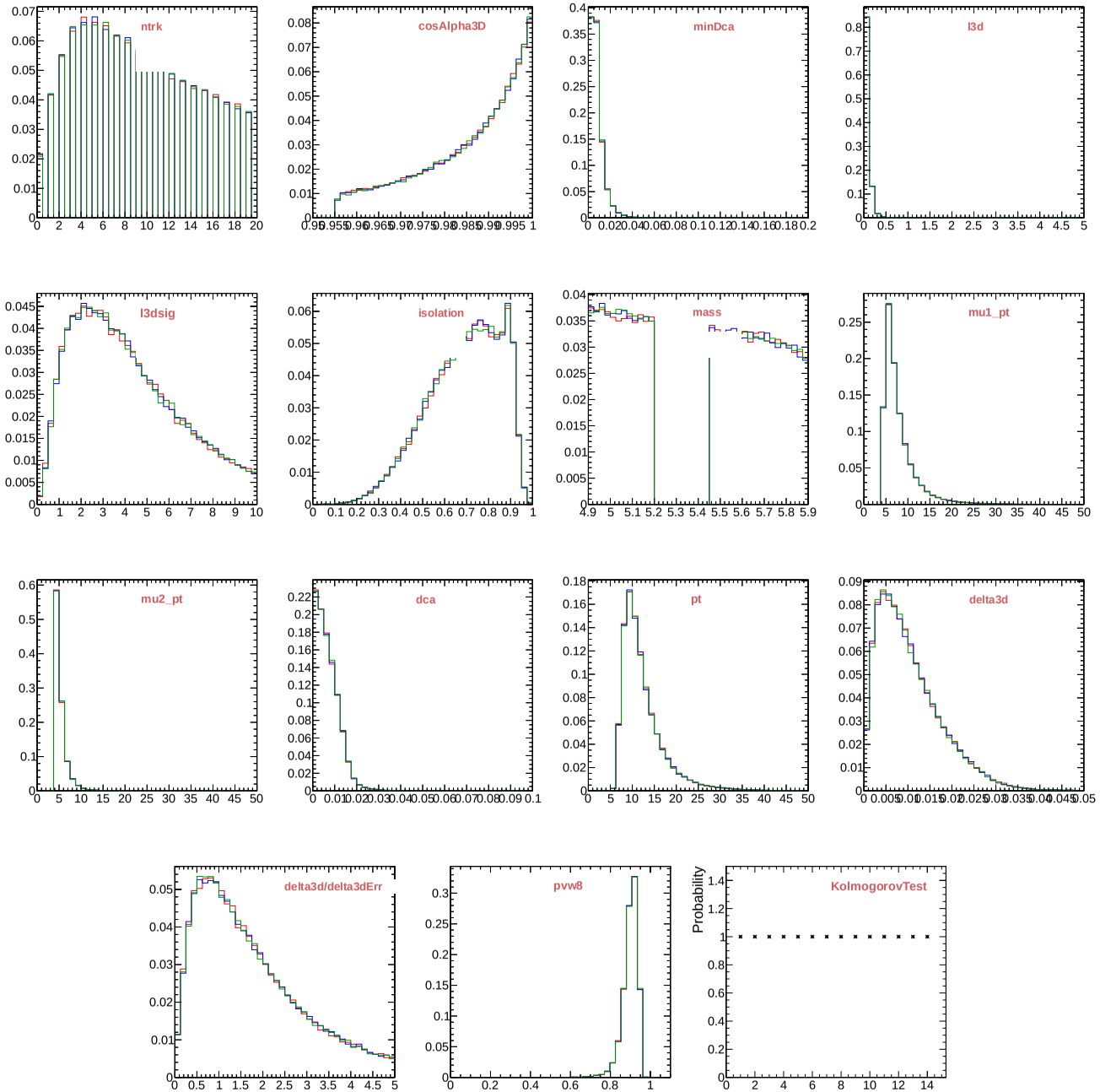

Figure 12: Overlay of BDT training variable distributions in data sideband background for events of the three subsets in the endcap. The plot on the bottom right summarizes all KS probablities.

	0		1		2	
rank	variable	separation	variable	separation	variable	separation
1	pvips	1.672e-01	iso	1.512e-01	iso	1.419e-01
2	iso	1.558e-01	pvips	1.288e-01	pvips	1.416e-01
3	alpha	1.323e-01	alpha	1.165e-01	alpha	1.399e-01
4	chi2dof	9.416e-02	pt	8.606e-02	pt	1.012e-01
5	fls3d	8.451e-02	chi2dof	8.119e-02	fls3d	9.344e-02
6	closetrk	8.059e-02	maxdoca	7.686e-02	closetrk	9.214e-02
7	docatrk	7.987e-02	fls3d	7.685e-02	chi2dof	8.138e-02
8	pt	6.259e-02	docatrk	7.453e-02	maxdoca	5.832e-02
9	eta	4.937e-02	closetrk	7.215e-02	eta	5.510e-02
10	pvip	4.810e-02	eta	6.899e-02	docatrk	4.799e-02
11	maxdoca	4.554e-02	pvip	6.686e-02	pvip	4.703e-02

Table 3: Variable ranking for events of the three different event samples in the barrel after BDT training.

	0		1		2	
rank	variable	separation	variable	separation	variable	separation
1	alpha	1.615e-01	alpha	1.660e-01	pvips	1.813e-01
2	pvips	1.448e-01	pvips	1.631e-01	alpha	1.648e-01
3	iso	1.391e-01	iso	1.487e-01	iso	1.397e-01
4	closetrk	1.004e-01	chi2dof	8.619e-02	maxdoca	8.805e-02
5	fls3d	7.556e-02	closetrk	8.554e-02	pt	7.196e-02
6	pvip	7.449e-02	fls3d	7.863e-02	fls3d	6.981e-02
7	maxdoca	6.504e-02	pvip	7.713e-02	closetrk	6.811e-02
8	chi2dof	6.250e-02	pt	5.923e-02	chi2dof	6.362e-02
9	docatrk	5.946e-02	eta	5.133e-02	pvip	5.797e-02
10	pt	5.929e-02	maxdoca	4.312e-02	eta	5.377e-02
11	eta	5.779e-02	docatrk	4.100e-02	docatrk	4.089e-02

Table 4: Variable ranking for events of the three different event samples in the endcaps after BDT training.

4 Boosted Decision Tree

The inclusive samples are split in three different subsamples according to the rule $index = eventNumber\%3$. These samples are then used as follows:

- events of type 0: analyzed by BDT0, trained on type-1 events, tested on type-2 events
- events of type 1: analyzed by BDT1, trained on type-2 events, tested on type-0 events
- events of type 2: analyzed by BDT2, trained on type-0 events, tested on type-1 events

for the training and testing.

Tables **??** and **??** show the ranking of variables before the BDT training.

Sample	Type 0	Type 1	Type 2
Signal barrel	11235	11074	11042
Signal endcaps	6686	6589	6622
Background barrel	27338	27091	27232
Background endcaps	34455	34583	34494

Table 5: Number of events per type for signal and background events in the barrel and endcap.

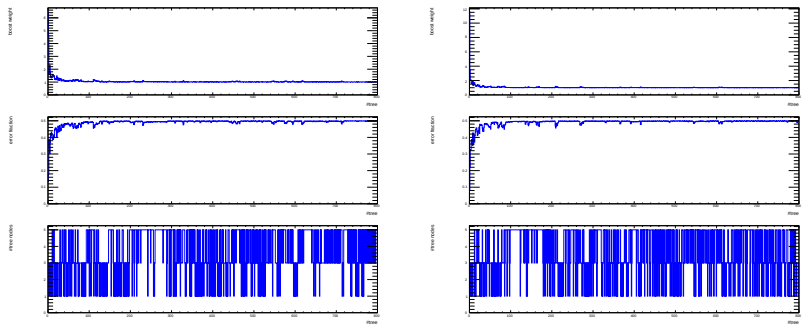

Figure 13: TMVA BDT charaterization plots for the barrel (left) and the endcap (right). Shown versus the tree number is the boost weight (top) and the event misclassification rate (middle), and the number of nodes before pruning (bottom).

Tables **??** shows the number of candidates in each of the subsamples. The events are after all preselections including muon-id (tight muon).

Figure 13 shows control plots for the BDT training.

5 Cut and count analysis

5.1 optimization

The same varibale set as used for MVA training is employed. The Simulating Annealing method in TMVA is used. The cuts are selected such that the selection signal efficiency matches that of the BDT.

```
Barrel:
 5.66532 < "pt" <= 108.395
 -1.34013 < "eta" <= 1.90538
 13.4938 < "fls3d" <= 113.735
 -0.00248177 < "alpha" <= 0.0554104
 -0.000113258 < "maxdoca" <= 0.0140014
 -0.00089438 < "pvip" <= 0.055899
 0.0869982 < "pvips" <= 4.19143
 0.425172 < "iso" <= 1.03777
 0.00903932 < "docatrk" <= 0.196985
 -0.0104609 < "closetrk" <= 8.94004
 -0.0949024 < "chi2dof" <= 5.55102

Endcaps:
6.81716 < "pt" <= 58.3142
-2.26185 < "eta" <= 2.35863
12.9774 < "fls3d" <= 122.734
-0.00186433 < "alpha" <= 0.236627
-0.000172019 < "maxdoca" <= 0.0192271
0.000376399 < "pvip" <= 0.0379179
0.0897054 < "pvips" <= 1.20388
0.59898 < "iso" <= 1.2262
0.011315 < "docatrk" <= 0.163787
-0.196135 < "closetrk" <= 17.3713
-0.0797694 < "chi2dof" <= 3.64842
```

5.2 blinded results

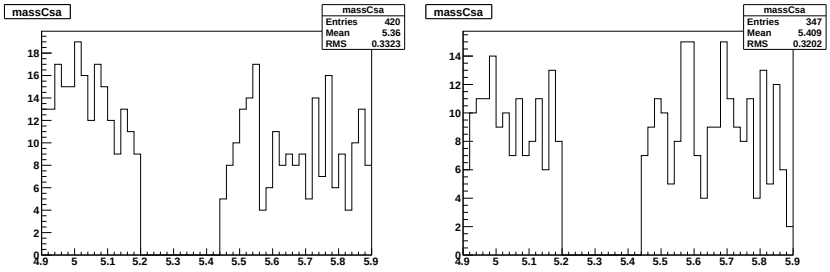

Figure 14: Blinded cut results for barrel (left) and endcaps (right).

5.3 unblind

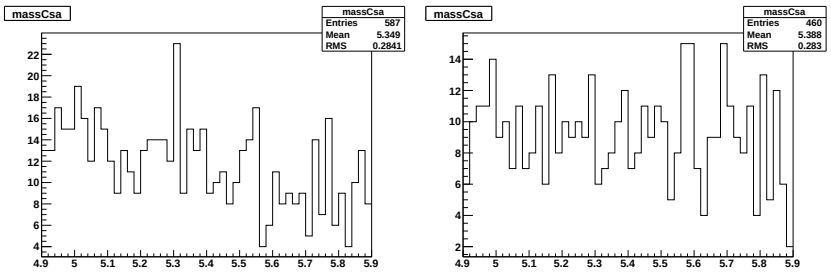

Figure 15: Unblinded cut results for barrel (left) and endcaps (right).

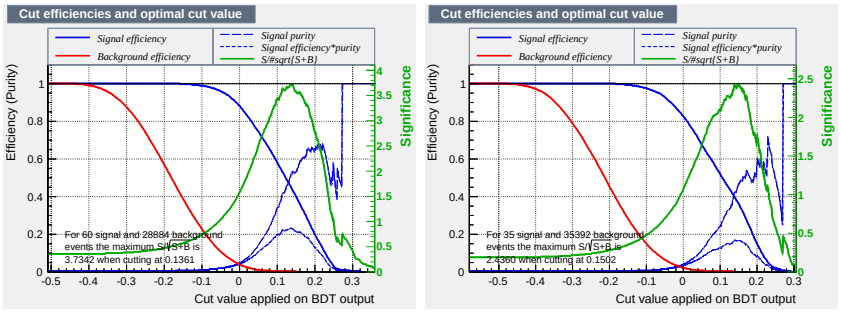

Figure 16: Optimal BDT cut value for barrel (left) and endcaps (right).

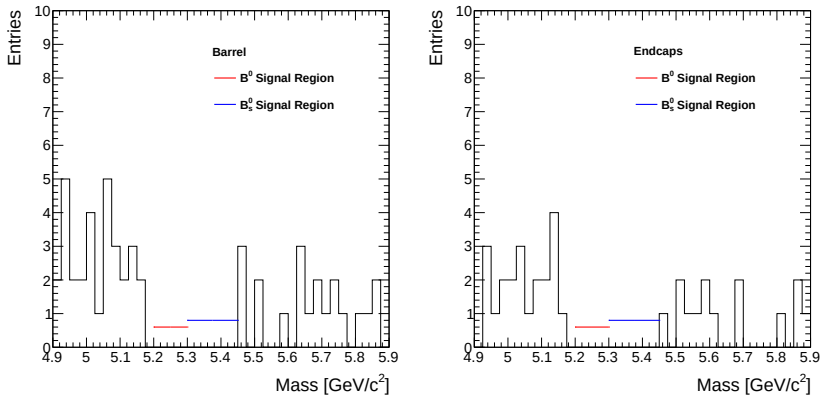

Figure 17: Blinded invariant mass distribution for all candidates passing the BDT selection for barrel (left) and endcaps (right).

6 BDT analysis

Figures 16 show the optimal value of the BDT cut for the estimated numbers of signal and background events.

Figures 17 show the blinded invariant mass distribution after applying the BDT selection.

Figures 22 shows the unblinded invariant mass distribution after applying the BDT selection.

Figures

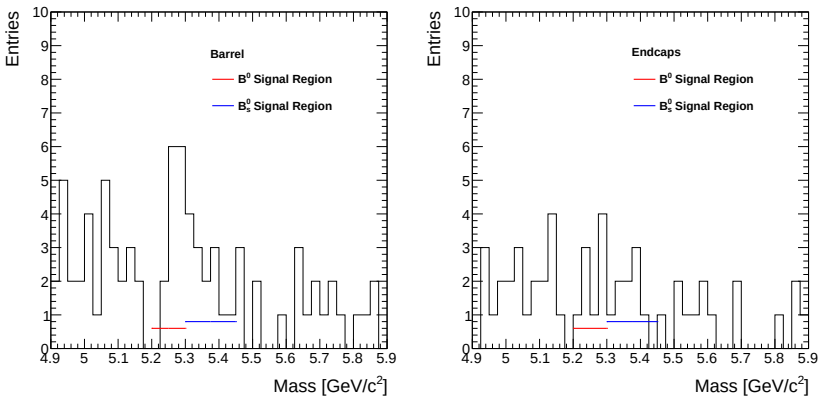

Figure 18: Unblinded invariant mass distribution for all candidates passing the BDT selection for barrel (left) and endcaps (right).

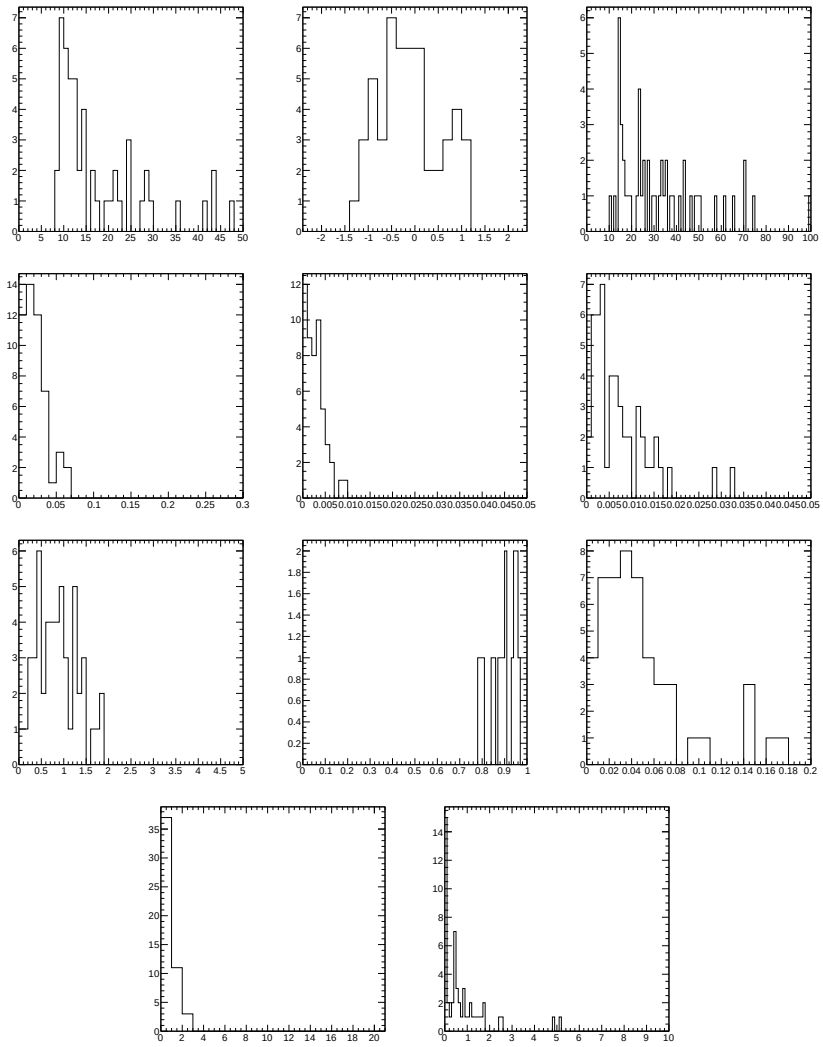

Figure 19: Variable distributions for the barrel after BDT cuts on blinded data.

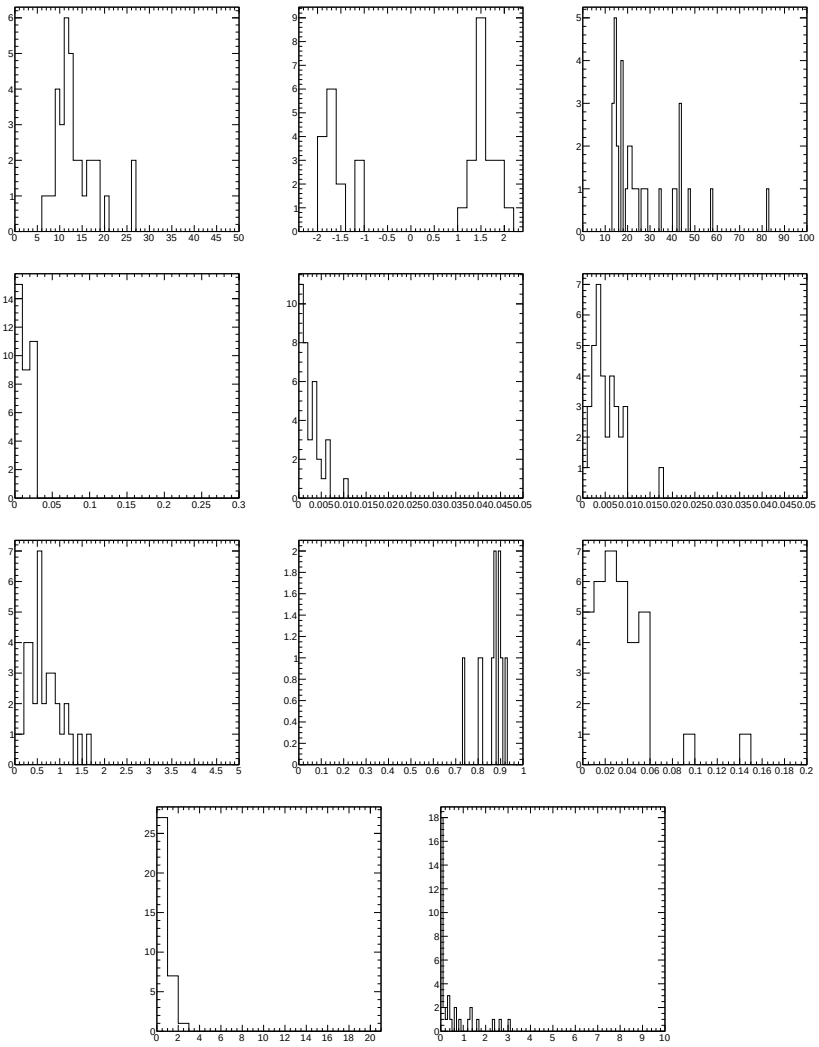

Figure 20: Variable distributions for the endcaps after BDT cuts on blinded data.

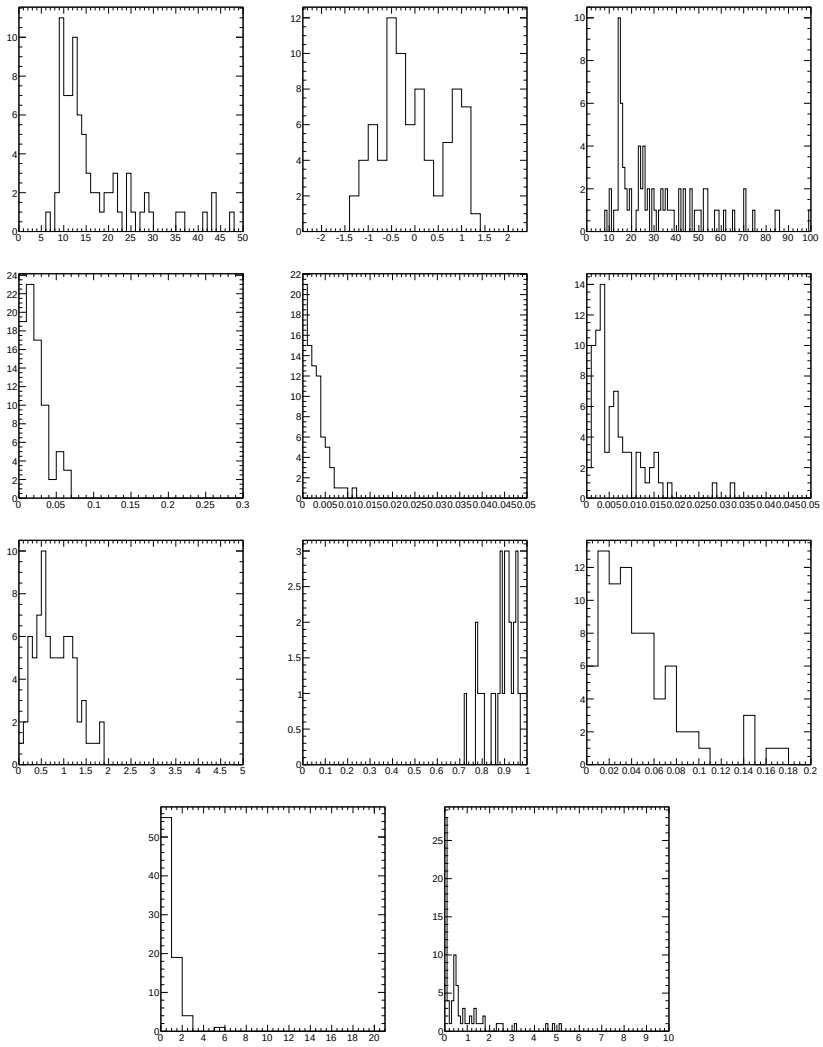

Figure 21: Variable distributions for the barrel after BDT cuts on unblinded data.

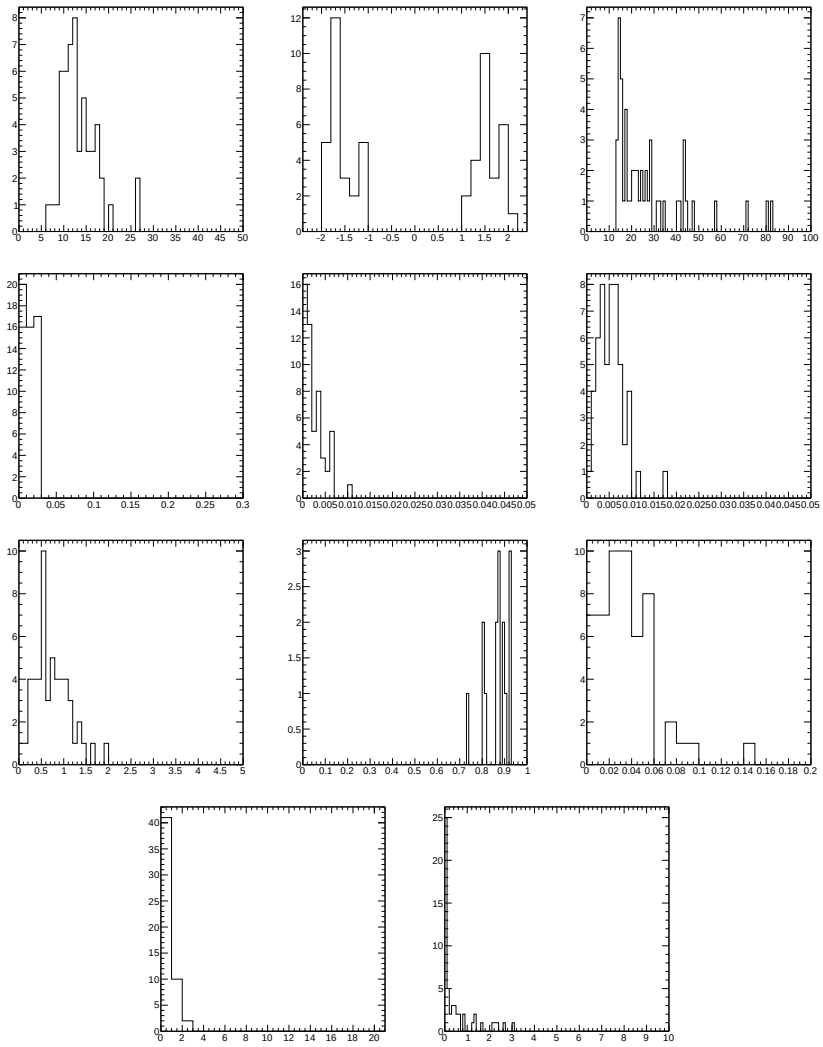

Figure 22: Variable distributions for the endcaps after BDT cuts on unblinded data.

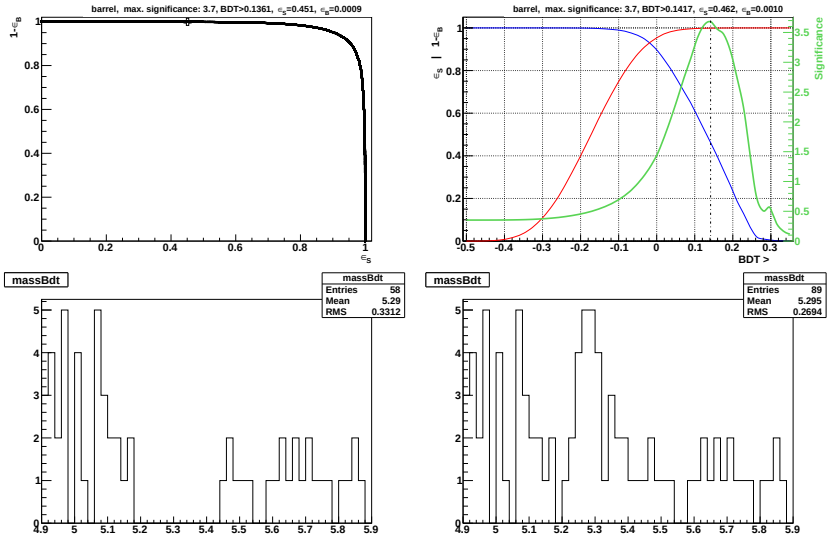

Figure 23: BDT barrel

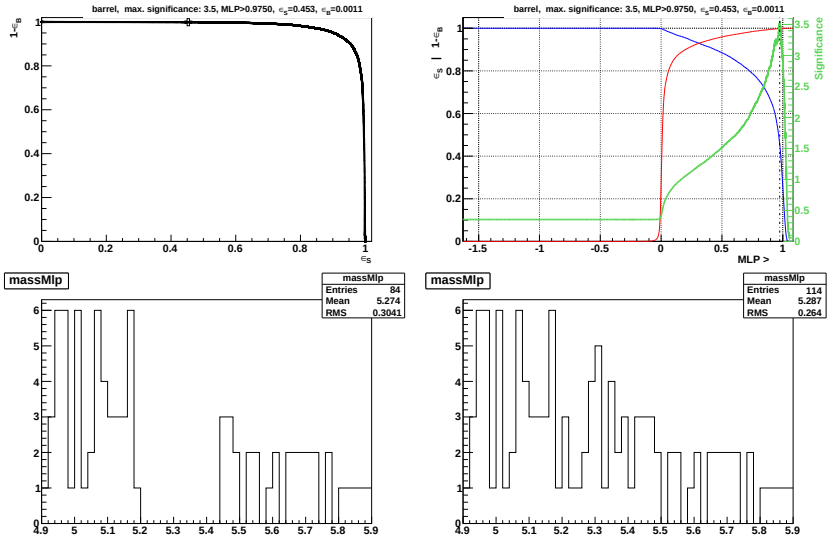

Figure 24: MLP barrel

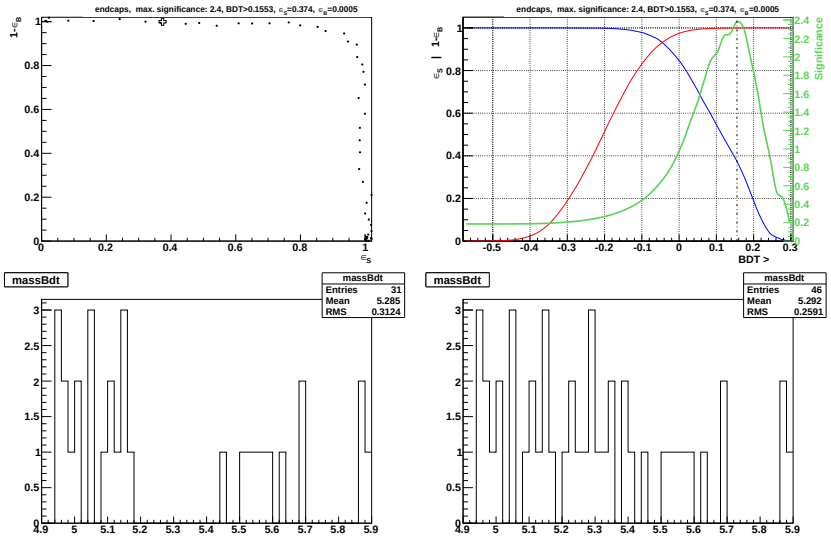

Figure 25: BDT endcaps

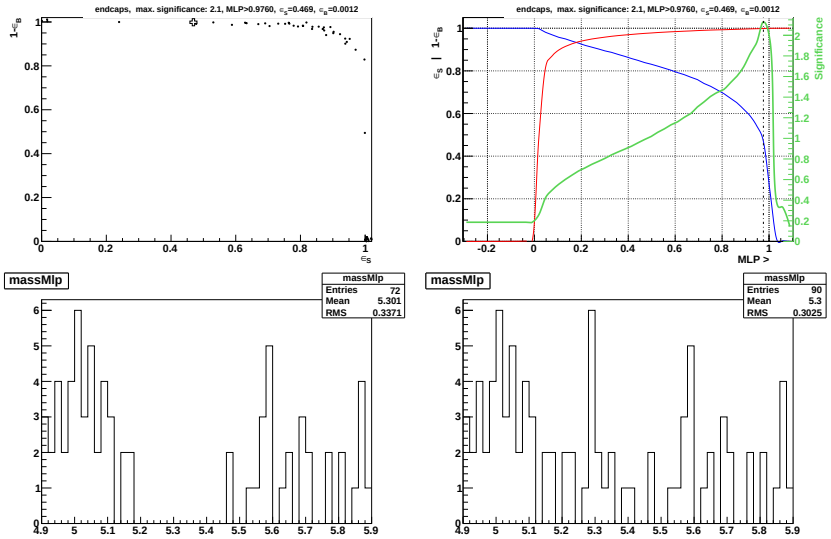

Figure 26: MLP endcaps

7 Normalization channel

7.1 datasets

7.2 selection

7.3 BDT

7.4 yields

8 Full dataset

9 Selection

9.1 datasets

9.2 muon identification

9.3 variable distributions, correlations, ranking

9.4 TMVA training

9.4.1 MLP

9.4.2 BDT

9.5 Normalization channel

9.5.1 MLP

9.5.2 BDT

9.6 Limits

10 Summary

References

[1] U. Langenegger et al. AN-12-358: "Search for $B_s \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ with the 2011 and 2012 data". Technical report, CMS Collaboration, 2012.