# $B_s^0 \to \mu^+\mu^-$ 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<br>/MuOnia/Run2012A-13Jul2012-v1/AOD<br>/MuOnia/Run2012A-recover-06Aug2012-v1/AOD<br>/MuOnia/Run2012B-13Jul2012-v1/AOD<br>/MuOnia/Run2012C-24Aug2012-v1/AOD<br>/MuOnia/Run2012C-PromptReco-v2/AOD<br>/MuOnia/Run2012C-EcalRecover_11Dec2012-v1/AOD<br>/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.

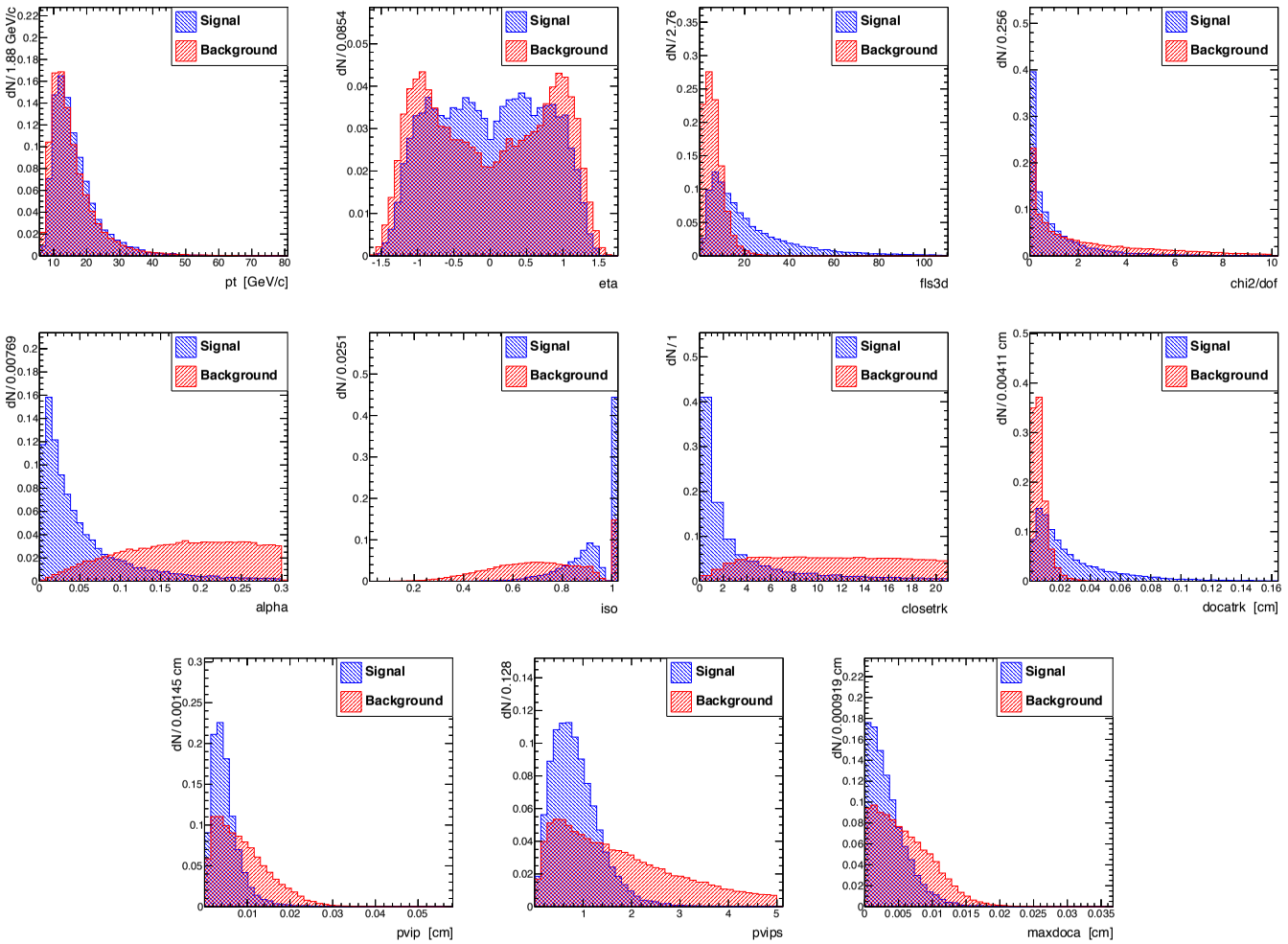


Figure 1: Standard TMVA plot of the input variables for the barrel BDT for signal (blue) and background (red). The background is extracted from data dimuon sidebands.

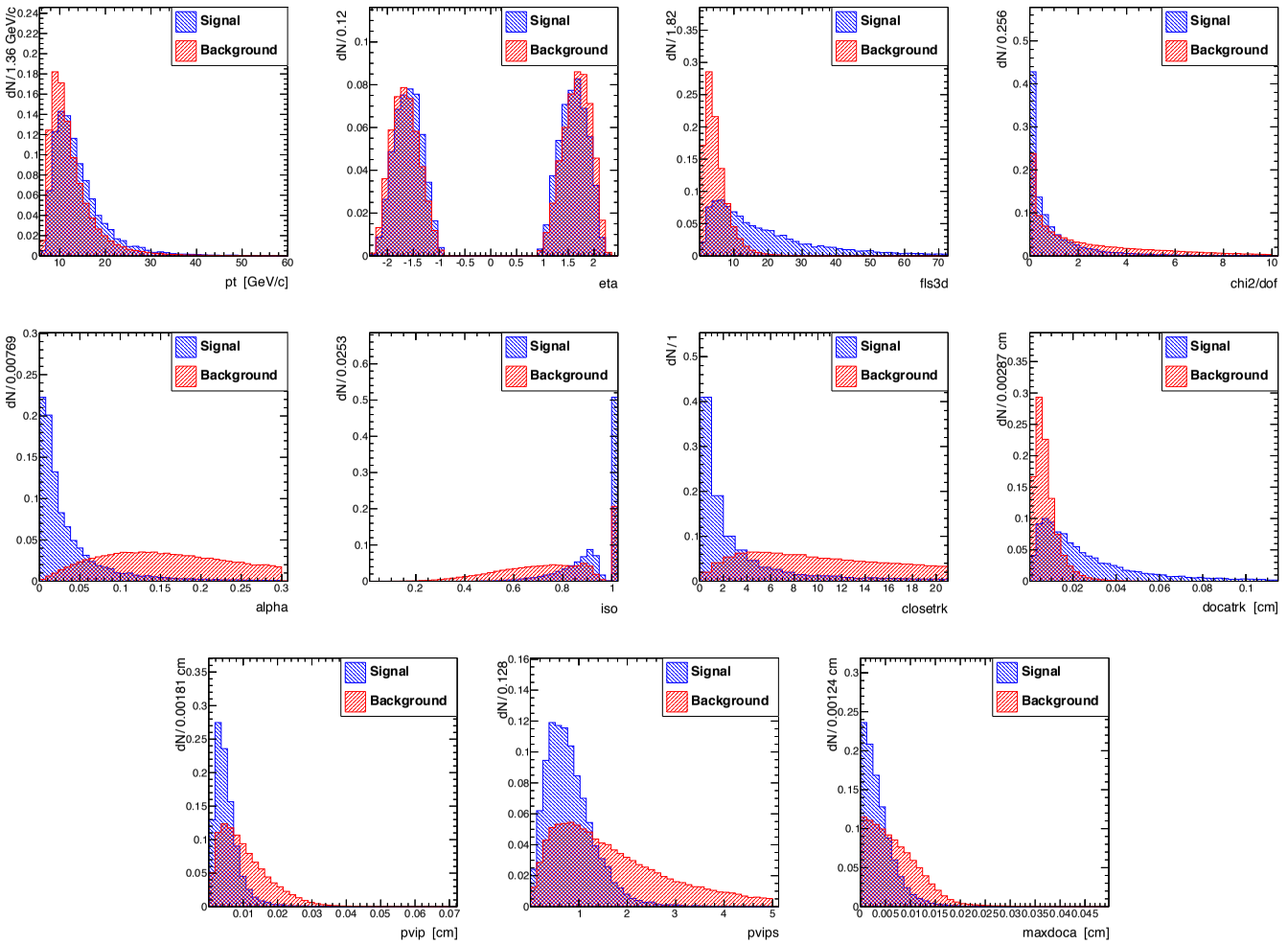


Figure 2: Standard TMVA plot of the input variables for the endcaps BDT for signal (blue) and background (red). The background is extracted from data dimuon sidebands.

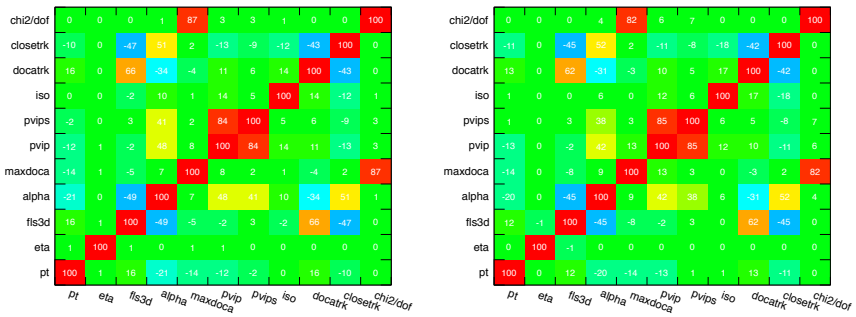


Figure 3: Correlation matrix for signal events in the barrel (left) and the endcap (right).

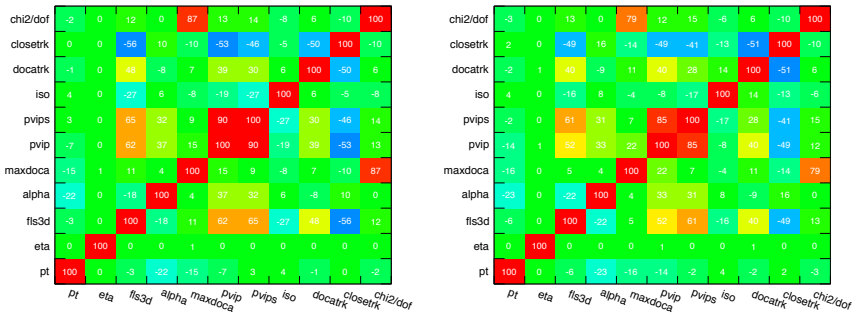


Figure 4: Correlation matrix for background events in the barrel (left) and the endcap (right).

| | 0 | | 1 | | 2 | |
|---|---|---|---|---|---|---|
| rank | variable | separation | variable | separation | variable | separation |
| 1 | alpha | 5.152e-01 | alpha | 5.187e-01 | alpha | 5.231e-01 |
| 2 | closetrk | 4.468e-01 | closetrk | 4.501e-01 | closetrk | 4.390e-01 |
| 3 | fls3d | 3.449e-01 | fls3d | 3.506e-01 | fls3d | 3.476e-01 |
| 4 | docatrk | 3.433e-01 | docatrk | 3.429e-01 | docatrk | 3.403e-01 |
| 5 | iso | 3.186e-01 | iso | 3.197e-01 | iso | 3.166e-01 |
| 6 | pvips | 2.223e-01 | pvips | 2.212e-01 | pvips | 2.201e-01 |
| 7 | pvip | 1.617e-01 | pvip | 1.562e-01 | pvip | 1.635e-01 |
| 8 | maxdoca | 1.069e-01 | maxdoca | 1.075e-01 | maxdoca | 1.106e-01 |
| 9 | chi2/dof | 1.014e-01 | chi2/dof | 1.019e-01 | chi2/dof | 1.071e-01 |
| 10 | eta | 2.601e-02 | eta | 2.483e-02 | eta | 2.552e-02 |
| 11 | pt | 9.944e-03 | pt | 1.004e-02 | pt | 1.009e-02 |

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 | 5.692e-01 | alpha | 5.674e-01 | alpha | 5.632e-01 |
| 2 | closetrk | 4.172e-01 | closetrk | 4.115e-01 | closetrk | 4.166e-01 |
| 3 | fls3d | 3.764e-01 | fls3d | 3.747e-01 | fls3d | 3.728e-01 |
| 4 | docatrk | 3.063e-01 | docatrk | 3.002e-01 | docatrk | 3.094e-01 |
| 5 | iso | 2.525e-01 | iso | 2.534e-01 | iso | 2.564e-01 |
| 6 | pvips | 2.193e-01 | pvips | 2.179e-01 | pvips | 2.233e-01 |
| 7 | pvip | 2.022e-01 | pvip | 2.008e-01 | pvip | 2.043e-01 |
| 8 | maxdoca | 1.272e-01 | maxdoca | 1.306e-01 | maxdoca | 1.293e-01 |
| 9 | chi2/dof | 1.047e-01 | chi2/dof | 1.057e-01 | chi2/dof | 1.078e-01 |
| 10 | pt | 3.555e-02 | pt | 3.862e-02 | pt | 3.534e-02 |
| 11 | eta | 1.208e-02 | eta | 1.299e-02 | eta | 1.072e-02 |

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

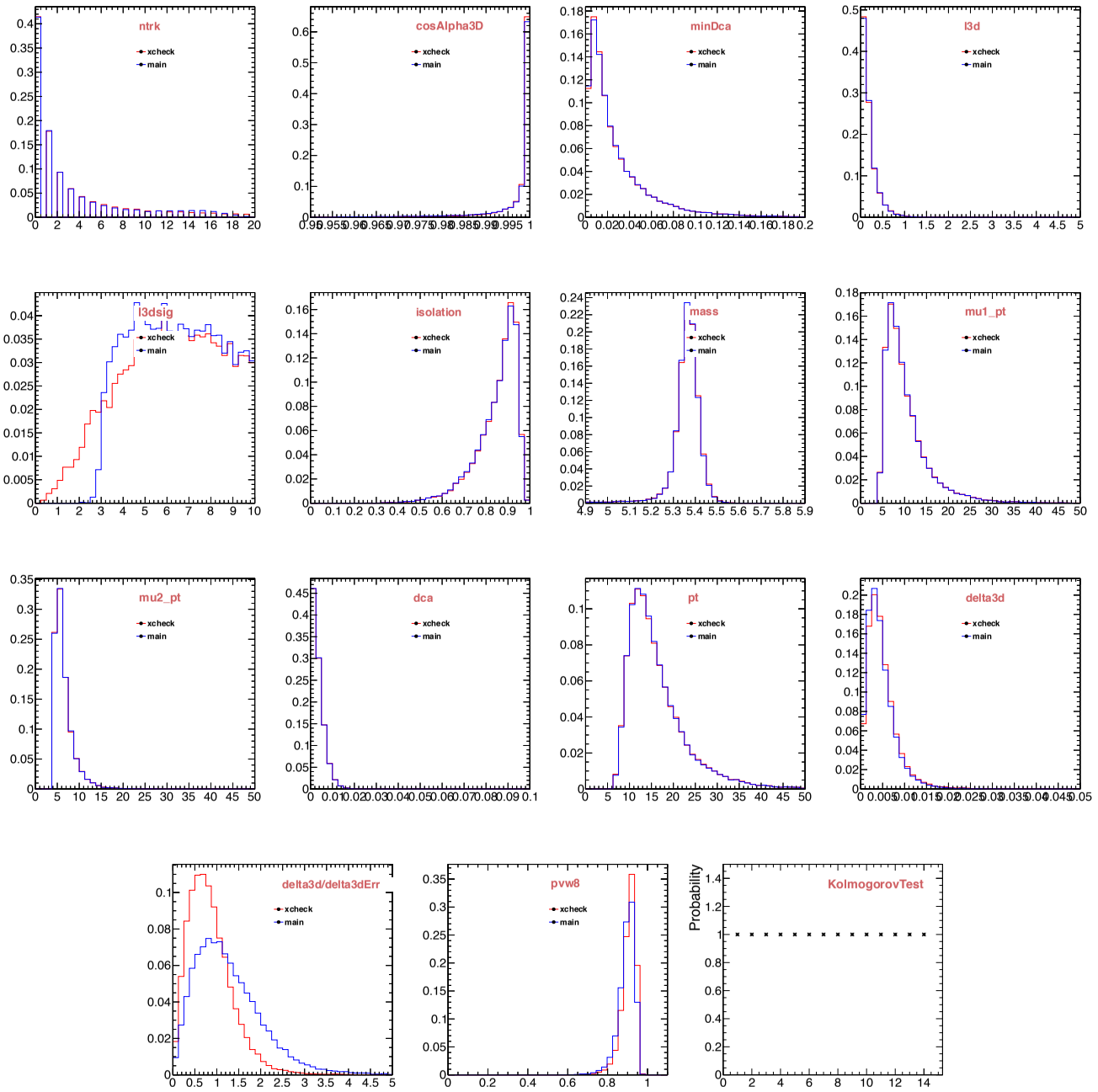


Figure 5: Variable comparisons between the main analysis and the cross-check analysis. Part I: MC barrel.

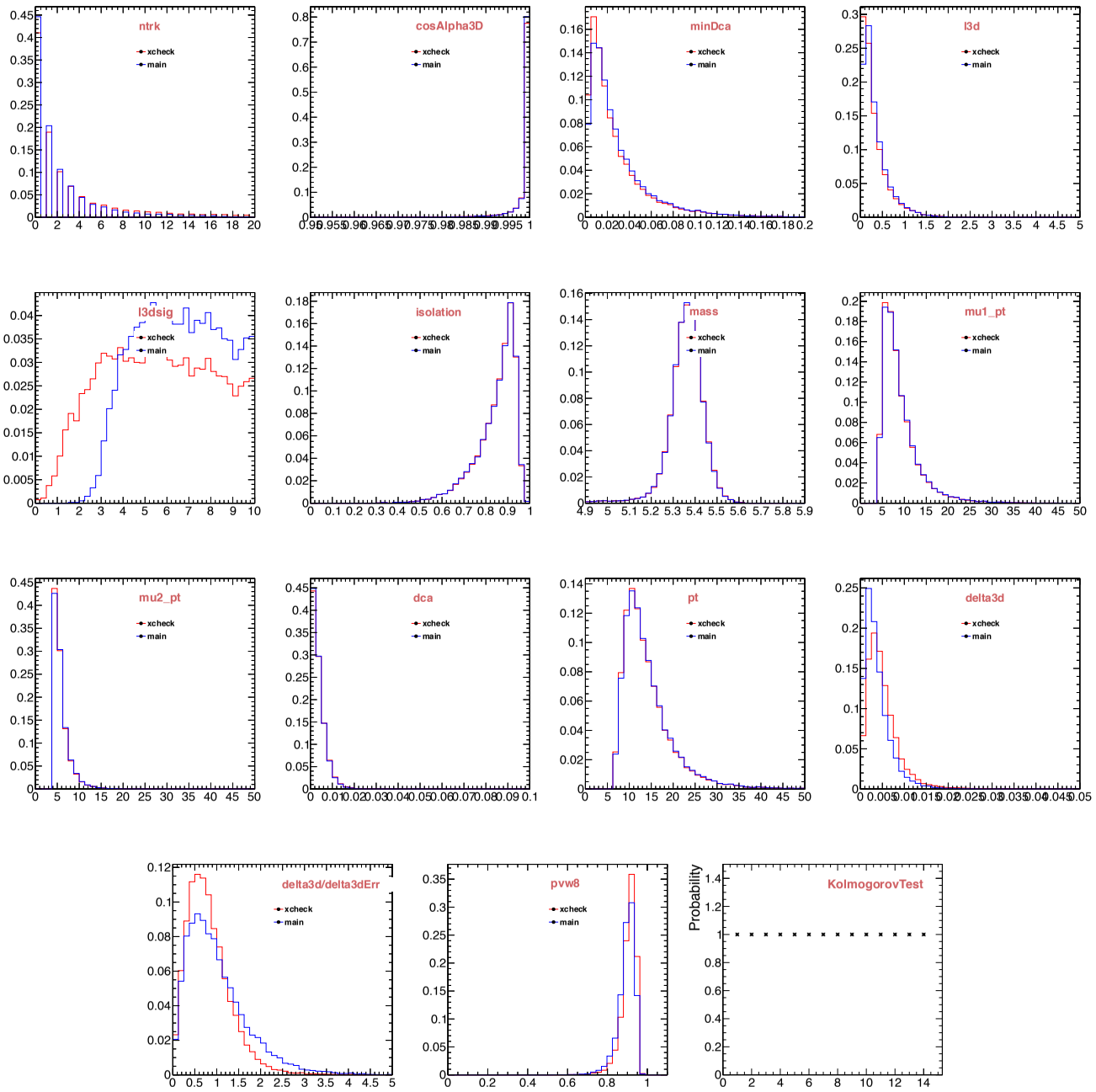


Figure 6: Variable comparisons between the main analysis and the cross-check analysis. Part I: MC endcaps.

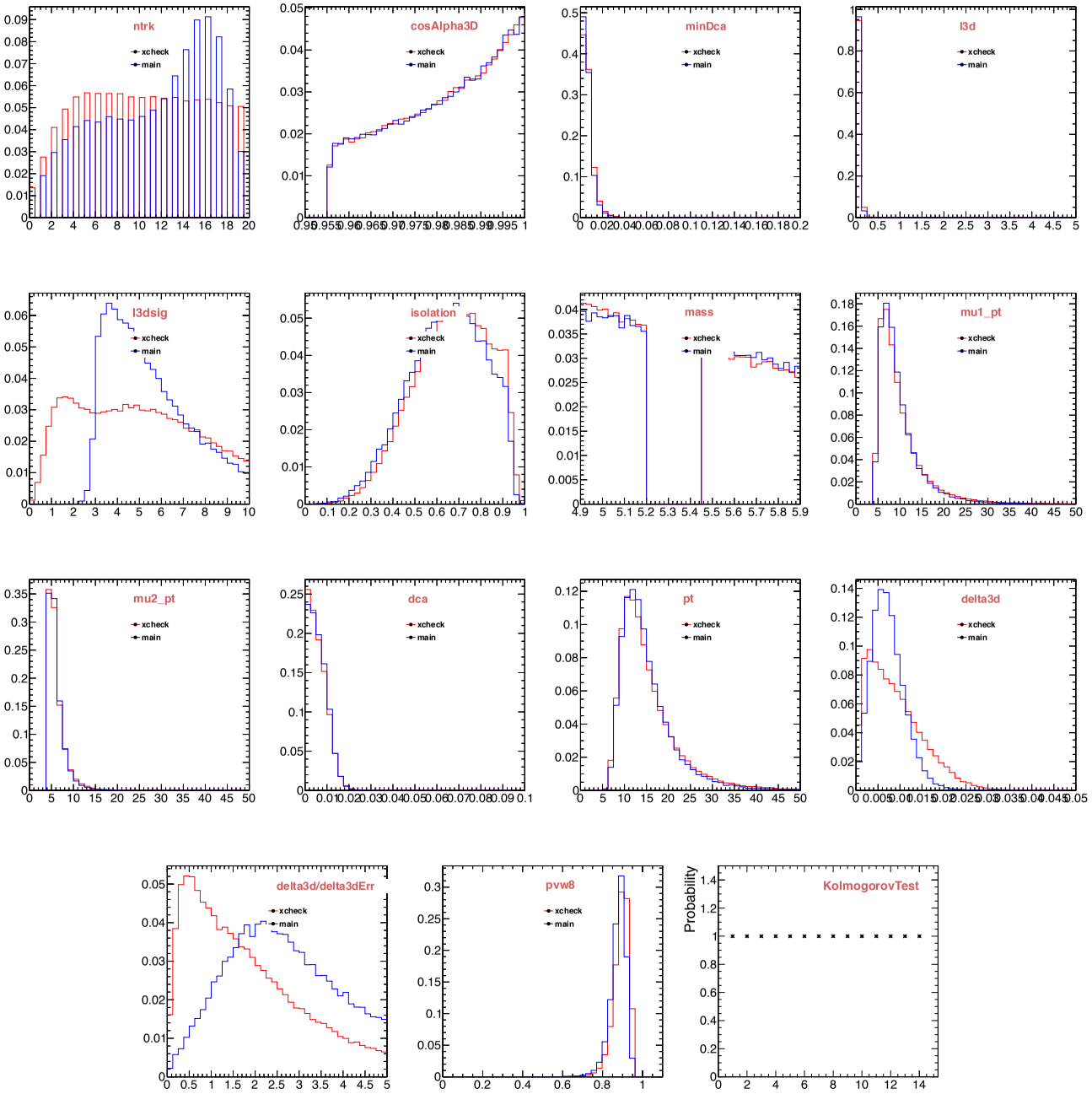


Figure 7: Variable comparisons between the main analysis and the cross-check analysis. Part I: Data barrel.

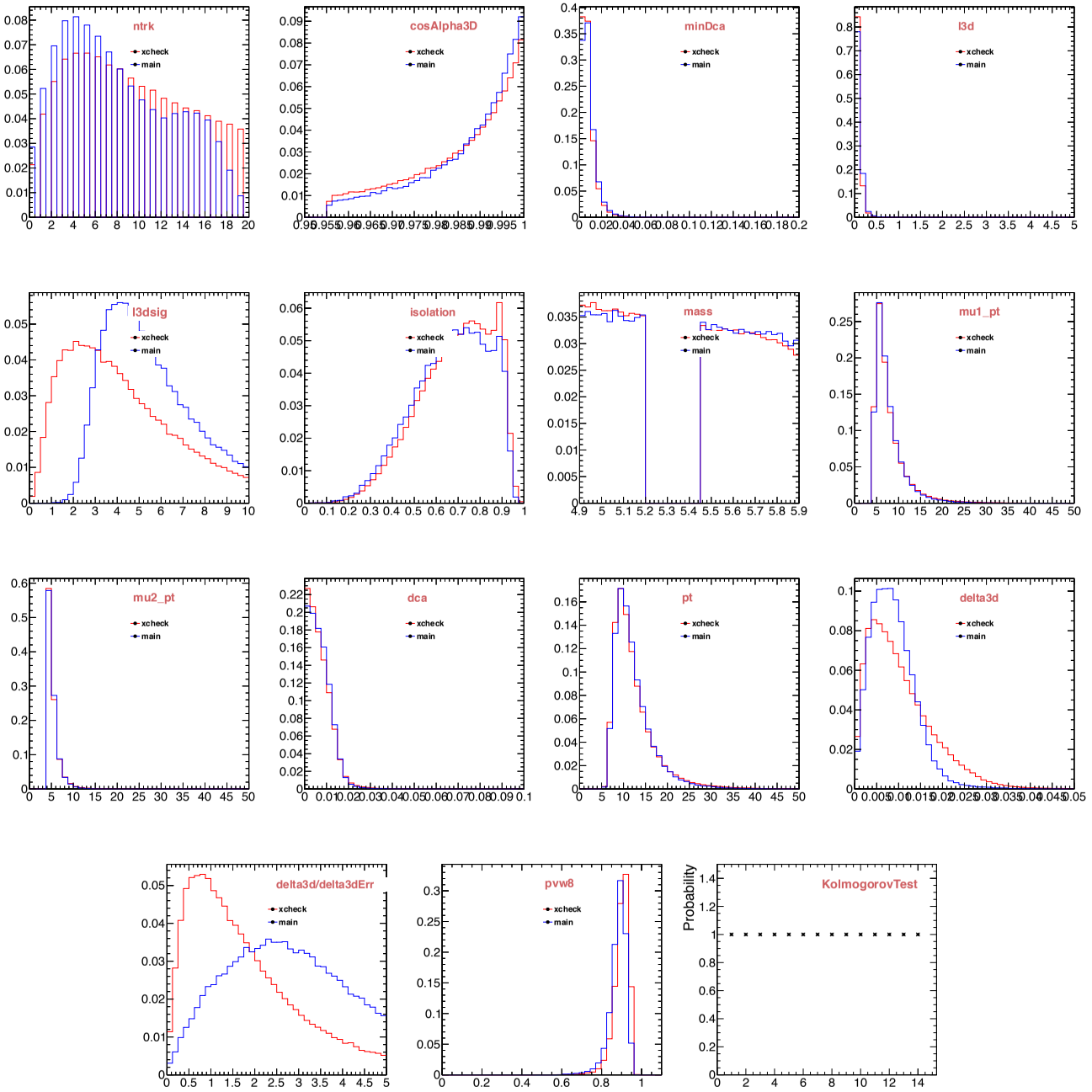


Figure 8: Variable comparisons between the main analysis and the cross-check analysis. Part I: Data endcaps.

| | 0 | | 1 | | 2 | |
|---|---|---|---|---|---|---|
| rank | variable | separation | variable | separation | variable | separation |
| 1 | pvips | 1.660e-01 | iso | 1.383e-01 | pvips | 1.485e-01 |
| 2 | iso | 1.295e-01 | pvips | 1.283e-01 | iso | 1.435e-01 |
| 3 | alpha | 1.249e-01 | alpha | 1.206e-01 | alpha | 1.388e-01 |
| 4 | fls3d | 9.997e-02 | pt | 1.026e-01 | fls3d | 1.070e-01 |
| 5 | pt | 8.929e-02 | fls3d | 1.017e-01 | pt | 9.982e-02 |
| 6 | closetrk | 8.100e-02 | closetrk | 7.681e-02 | closetrk | 9.170e-02 |
| 7 | chi2dof | 7.528e-02 | chi2dof | 7.167e-02 | chi2dof | 8.199e-02 |
| 8 | docatrk | 7.456e-02 | docatrk | 6.902e-02 | eta | 7.281e-02 |
| 9 | eta | 7.163e-02 | eta | 6.747e-02 | maxdoca | 5.140e-02 |
| 10 | pvip | 4.615e-02 | maxdoca | 6.372e-02 | pvip | 3.815e-02 |
| 11 | maxdoca | 4.177e-02 | pvip | 5.978e-02 | docatrk | 2.639e-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 | 1.648e-01 | alpha | 1.641e-01 | pvips | 1.750e-01 |
| 2 | pvips | 1.461e-01 | pvips | 1.555e-01 | alpha | 1.690e-01 |
| 3 | iso | 1.265e-01 | iso | 1.304e-01 | iso | 1.256e-01 |
| 4 | closetrk | 1.077e-01 | closetrk | 1.000e-01 | closetrk | 9.363e-02 |
| 5 | pt | 9.134e-02 | fls3d | 8.571e-02 | pt | 7.921e-02 |
| 6 | fls3d | 7.871e-02 | pt | 8.055e-02 | maxdoca | 7.662e-02 |
| 7 | maxdoca | 6.374e-02 | chi2dof | 7.770e-02 | chi2dof | 6.989e-02 |
| 8 | pvip | 5.972e-02 | maxdoca | 6.384e-02 | eta | 6.810e-02 |
| 9 | chi2dof | 5.492e-02 | pvip | 5.309e-02 | fls3d | 6.457e-02 |
| 10 | docatrk | 5.421e-02 | eta | 5.159e-02 | pvip | 4.433e-02 |
| 11 | eta | 5.220e-02 | docatrk | 3.759e-02 | docatrk | 3.403e-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 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 | 11713 | 11481 | 11500 |
| Signal endcaps | 7392 | 7318 | 7390 |
| Background barrel | 38206 | 37947 | 38308 |
| Background endcaps | 68327 | 68233 | 68157 |

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

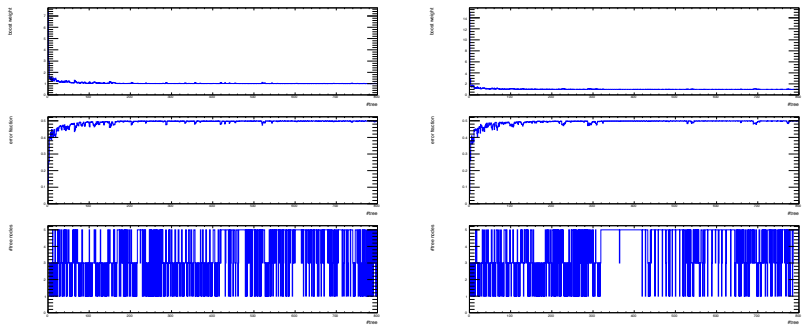

Figure 9: TMVA BDT charaterization plots for the barrel (left) and the endcap (right). Shown versus the tree number is the boost weight (top) and the event misclassification rate (middle), and the number of nodes before pruning (bottom).

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

Figure 9 shows control plots for the BDT training.

# 5 Cut and count analysis

## 5.1 optimization and blinded results

## 5.2 unblind

# 6 BDT analysis

## 6.1 training and overtraining

## 6.2 blinded results

## 6.3 unblind

# 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.