Feasibility Study of Measuring the Higgs Self-coupling Using the Muon Collider

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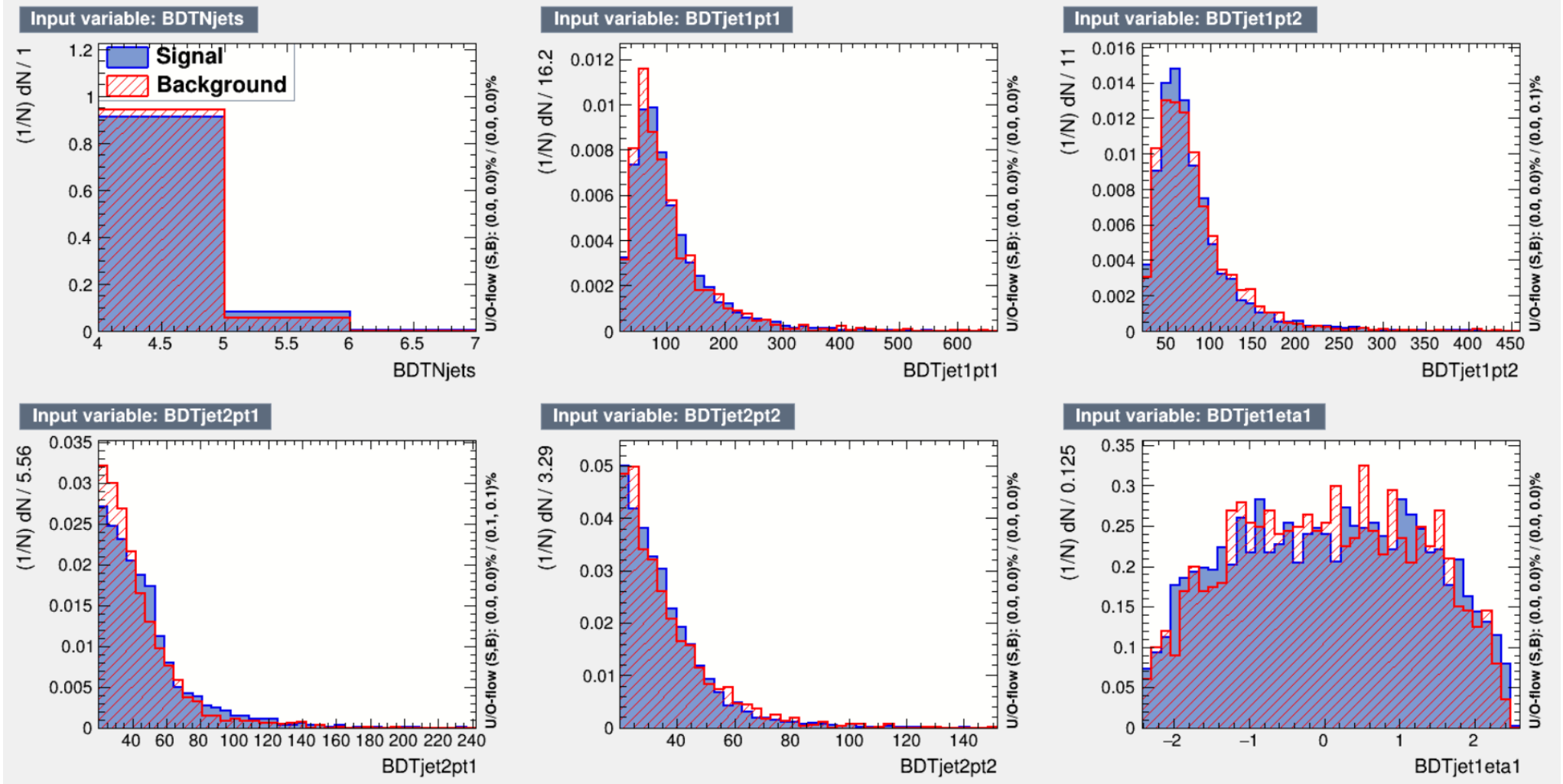
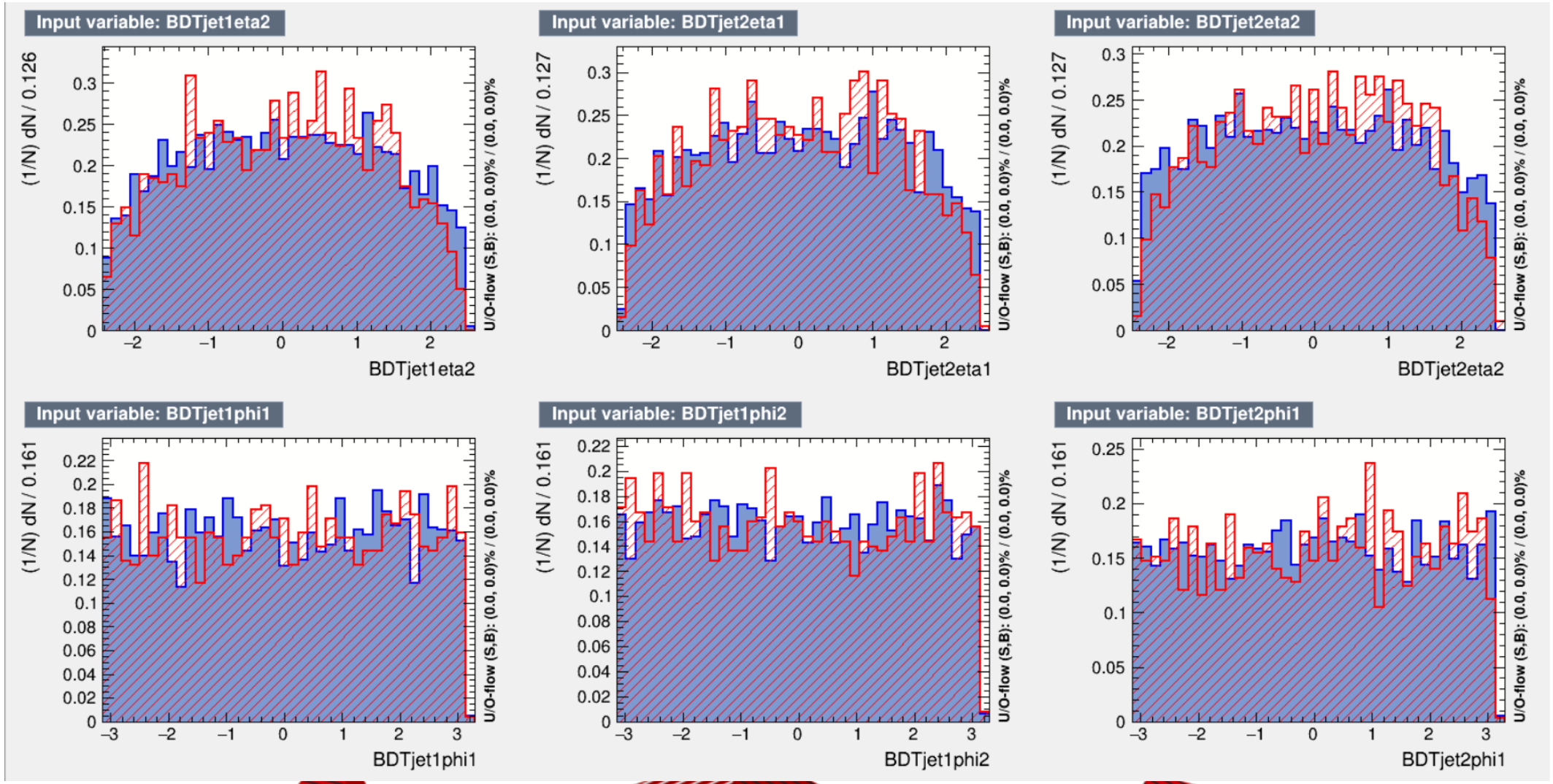
- Signal: $\mu^- + \mu^+ \rightarrow \nu_\mu + \bar{\nu}_\mu + H + H$ $(0.0008182 \pm 6.2\text{e} - 7\ \text{pb})$
- Background:
  - $\mu^- + \mu^+ \rightarrow \nu_\mu + \bar{\nu}_\mu + b + \bar{b} + Z$ $(0.03183 \pm 0.000025\ \text{pb})$
  - $\mu^- + \mu^+ \rightarrow \nu_\mu + \bar{\nu}_\mu + b + \bar{b} + H$ $(0.003771 \pm 3.1\text{e} - 6\ \text{pb})$
  - $\mu^- + \mu^+ \rightarrow \nu_\mu + \bar{\nu}_\mu + b + \bar{b} + b + \bar{b}$ $(0.0009237 \pm 7.2\text{e} - 7\ \text{pb})$

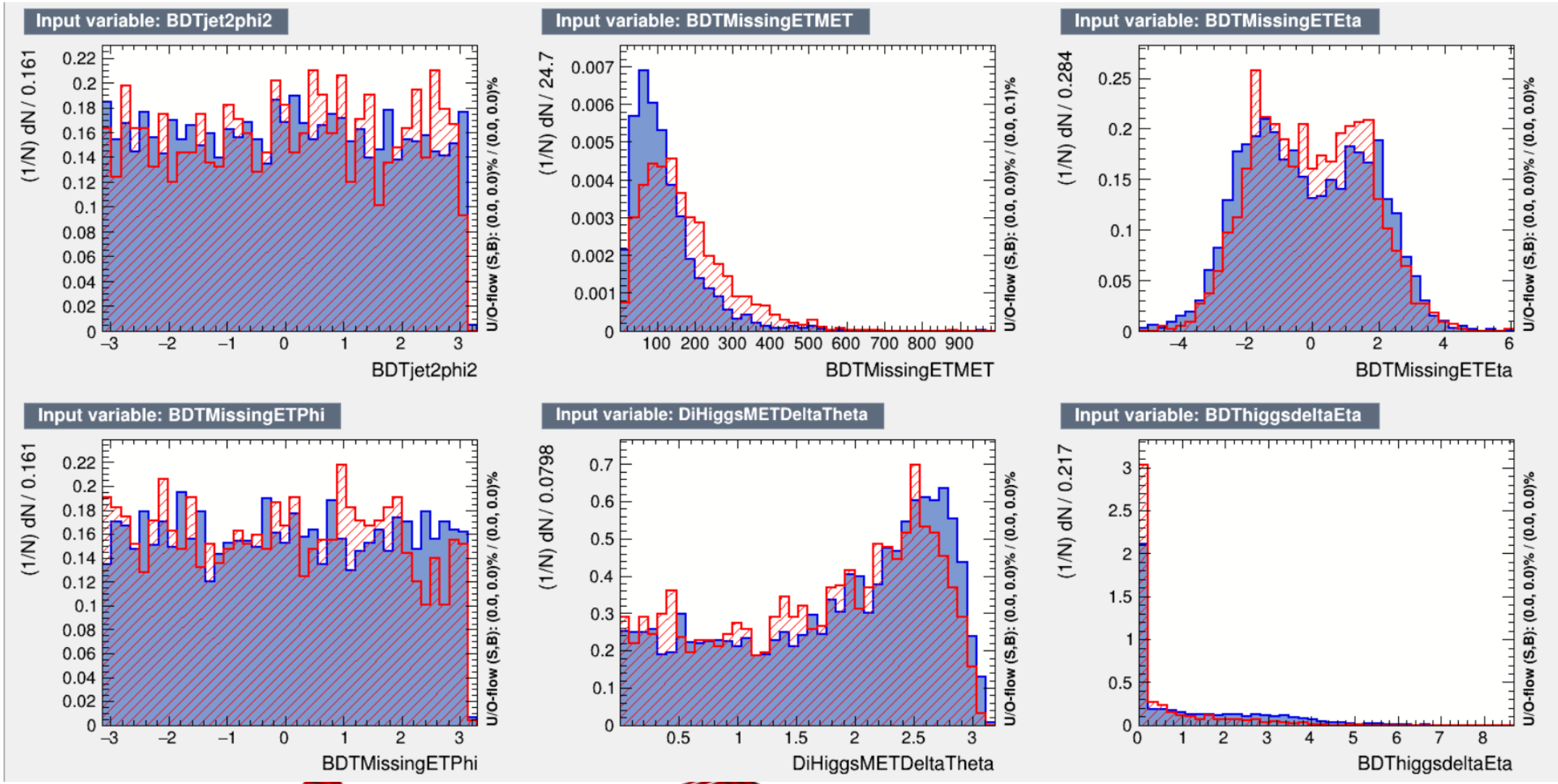
100k for each

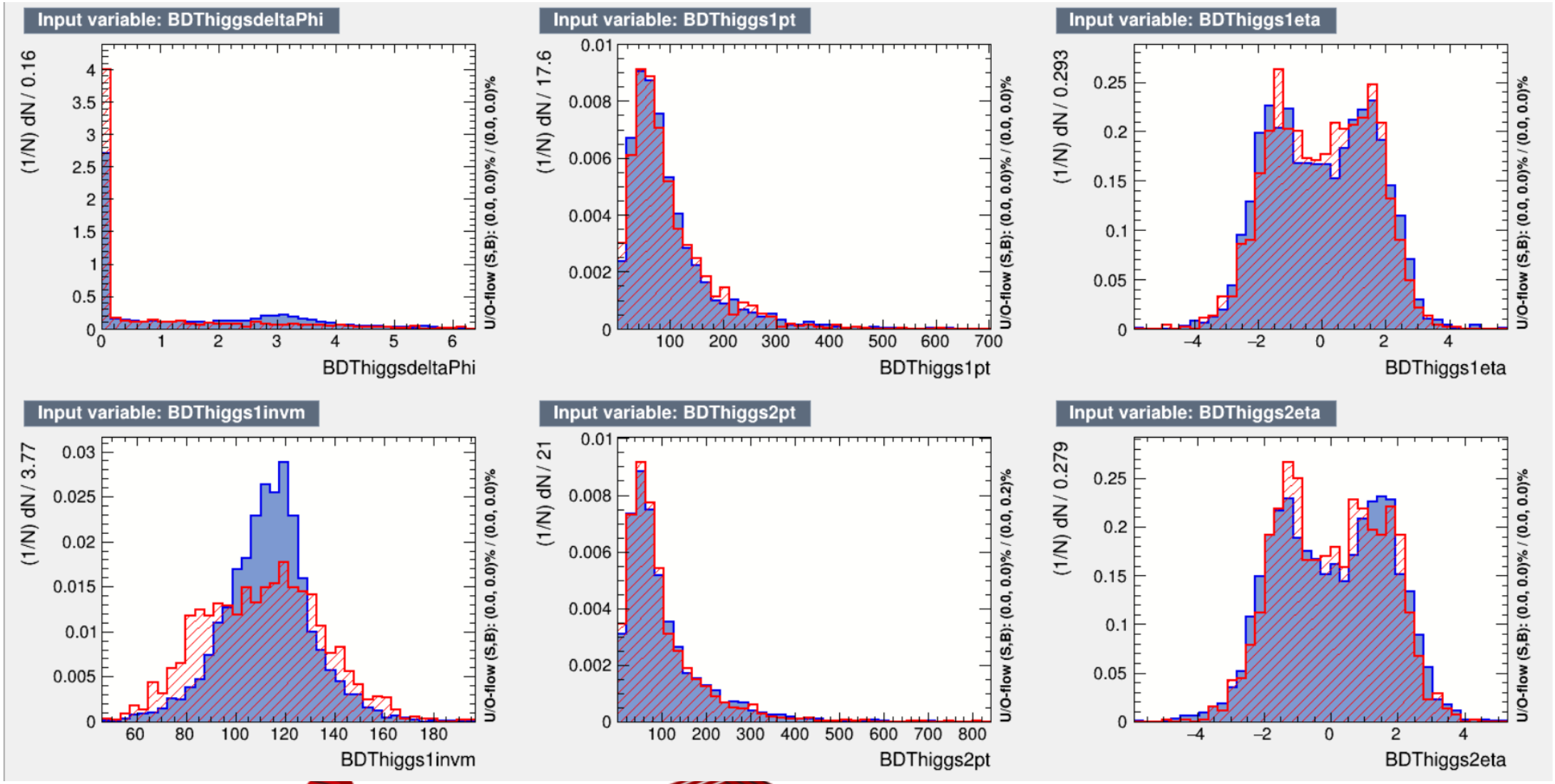
MVA to discriminate vvHH with dominant bkg vvbbZ

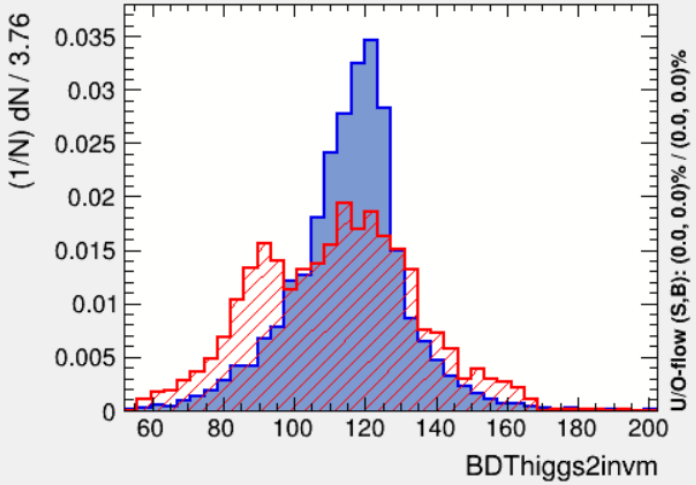
- With TMVA, a built-in package in ROOT
  - Support different ML approach:
    - Boosting Decision Tree
    - Multilayer perceptron
    - Deep Neural Network

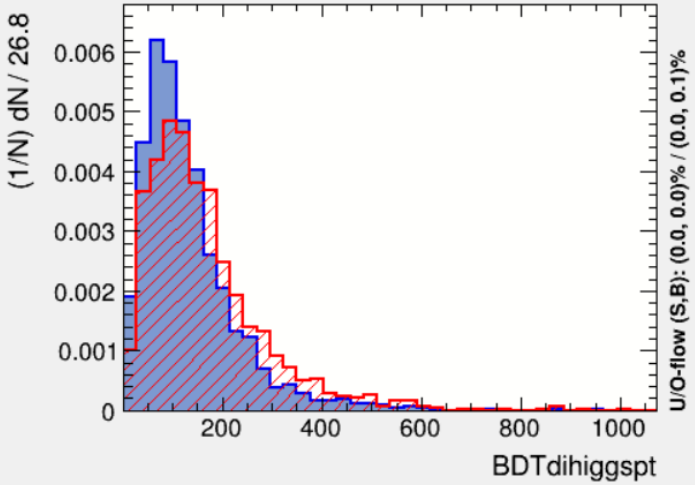

Input variable: BDTNjets
Signal
Background
(1/N) dN / 1
BDTNjets
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDTjet1pt1
(1/N) dN / 16.2
BDTjet1pt1
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDTjet1pt2
(1/N) dN / 11
BDTjet1pt2
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.1)%
Input variable: BDTjet2pt1
(1/N) dN / 5.56
BDTjet2pt1
U/O-flow (S,B): (0.0, 0.0)% / (0.1, 0.1)%
Input variable: BDTjet2pt2
(1/N) dN / 3.29
BDTjet2pt2
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDTjet1eta1
(1/N) dN / 0.125
BDTjet1eta1
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

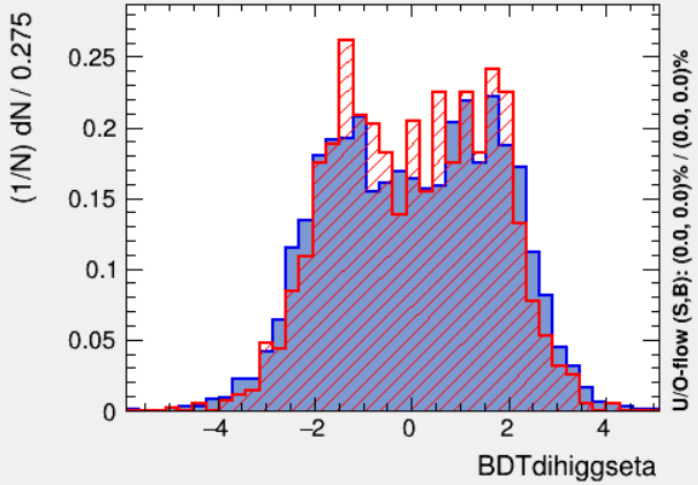

Input variable: BDTjet1eta2
(1/N) dN / 0.126
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDTjet1eta2
Input variable: BDTjet2eta1
(1/N) dN / 0.127
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDTjet2eta1
Input variable: BDTjet2eta2
(1/N) dN / 0.127
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDTjet2eta2
Input variable: BDTjet1phi1
(1/N) dN / 0.161
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDTjet1phi1
Input variable: BDTjet1phi2
(1/N) dN / 0.161
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDTjet1phi2
Input variable: BDTjet2phi1
(1/N) dN / 0.161
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
BDTjet2phi1

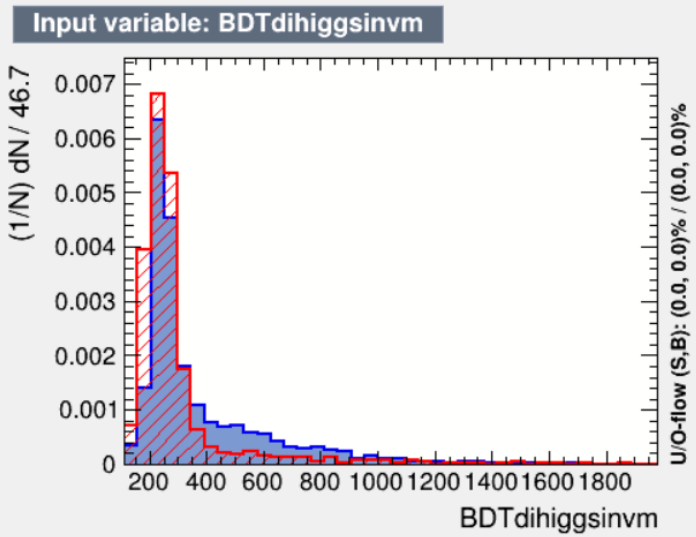

Input variable: BDTjet2phi2
(1/N) dN / 0.161
BDTjet2phi2
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDTMissingETMET
(1/N) dN / 24.7
BDTMissingETMET
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.1)%
Input variable: BDTMissingETEta
(1/N) dN / 0.284
BDTMissingETEta
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDTMissingETPhi
(1/N) dN / 0.161
BDTMissingETPhi
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: DiHiggsMETDeltaTheta
(1/N) dN / 0.0798
DiHiggsMETDeltaTheta
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDThiggsdeltaEta
(1/N) dN / 0.217
BDThiggsdeltaEta
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

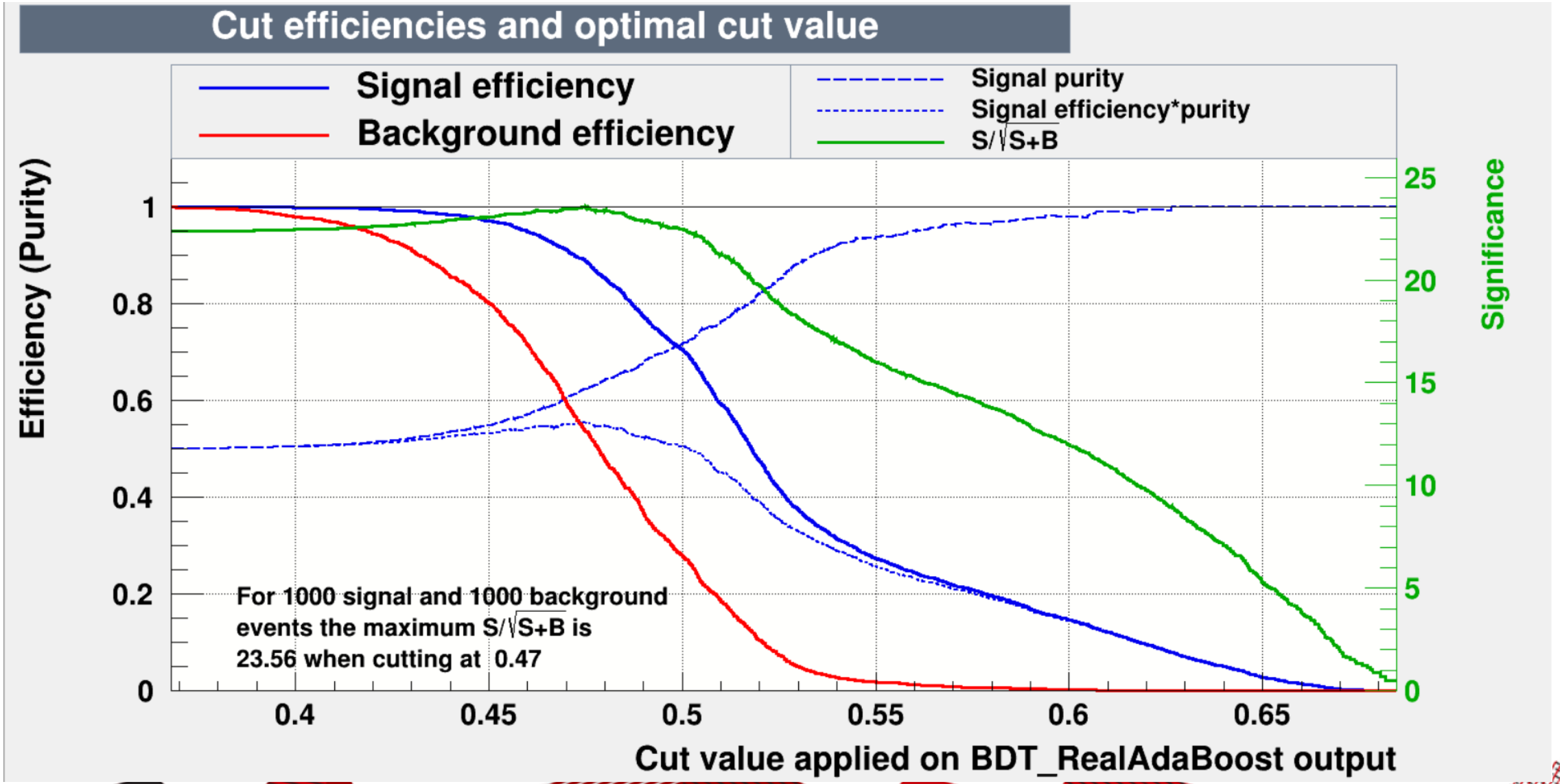

Input variable: BDThiggsdeltaPhi
(1/N) dN / 0.16
BDThiggsdeltaPhi
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDThiggs1pt
(1/N) dN / 17.6
BDThiggs1pt
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDThiggs1eta
(1/N) dN / 0.293
BDThiggs1eta
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDThiggs1invm
(1/N) dN / 3.77
BDThiggs1invm
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: BDThiggs2pt
(1/N) dN / 21
BDThiggs2pt
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.2)%
Input variable: BDThiggs2eta
(1/N) dN / 0.279
BDThiggs2eta
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

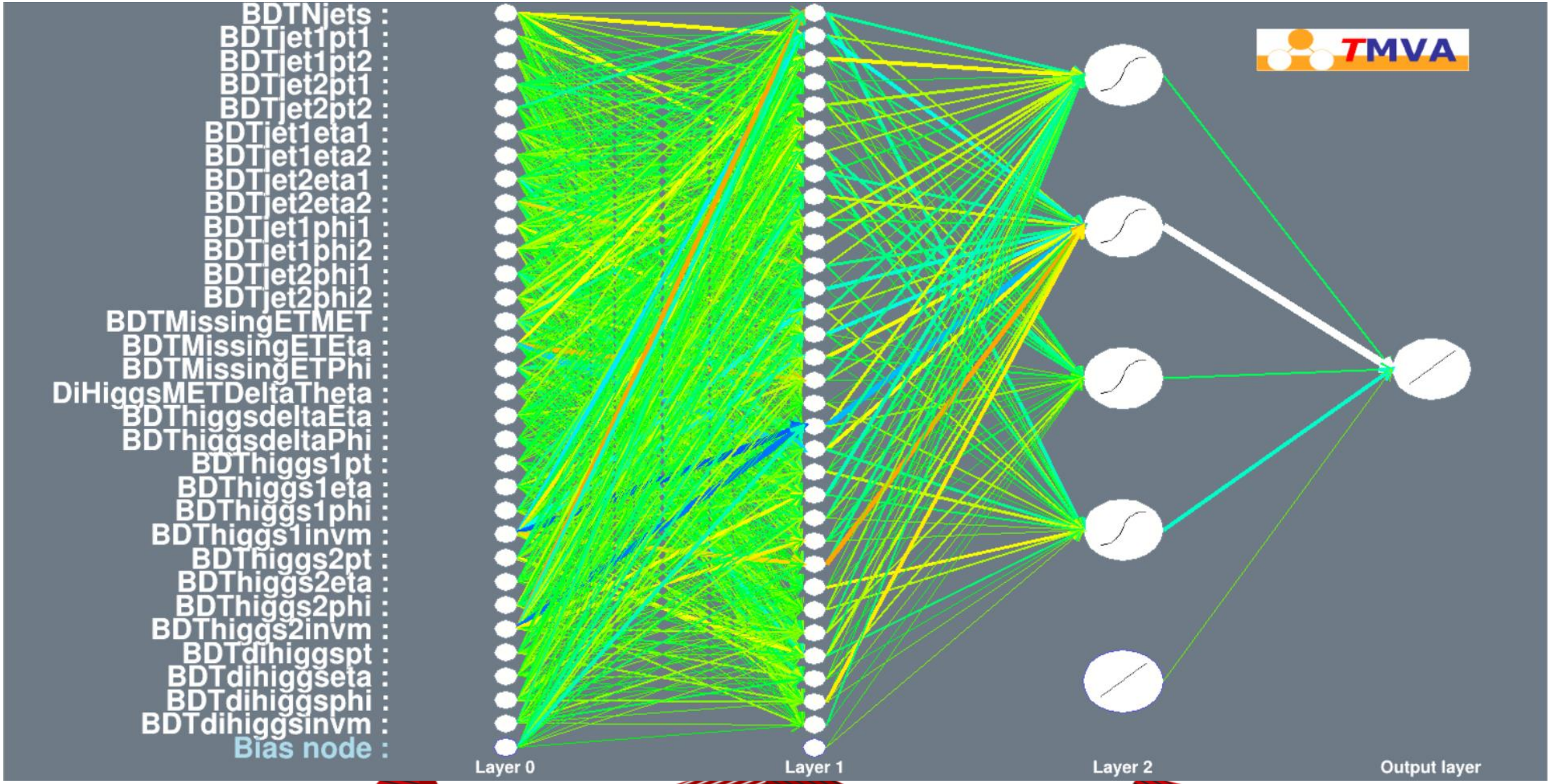

Input variable: BDThiggs2invm
(1/N) dN / 3.76
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
60 80 100 120 140 160 180 200
BDThiggs2invm
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

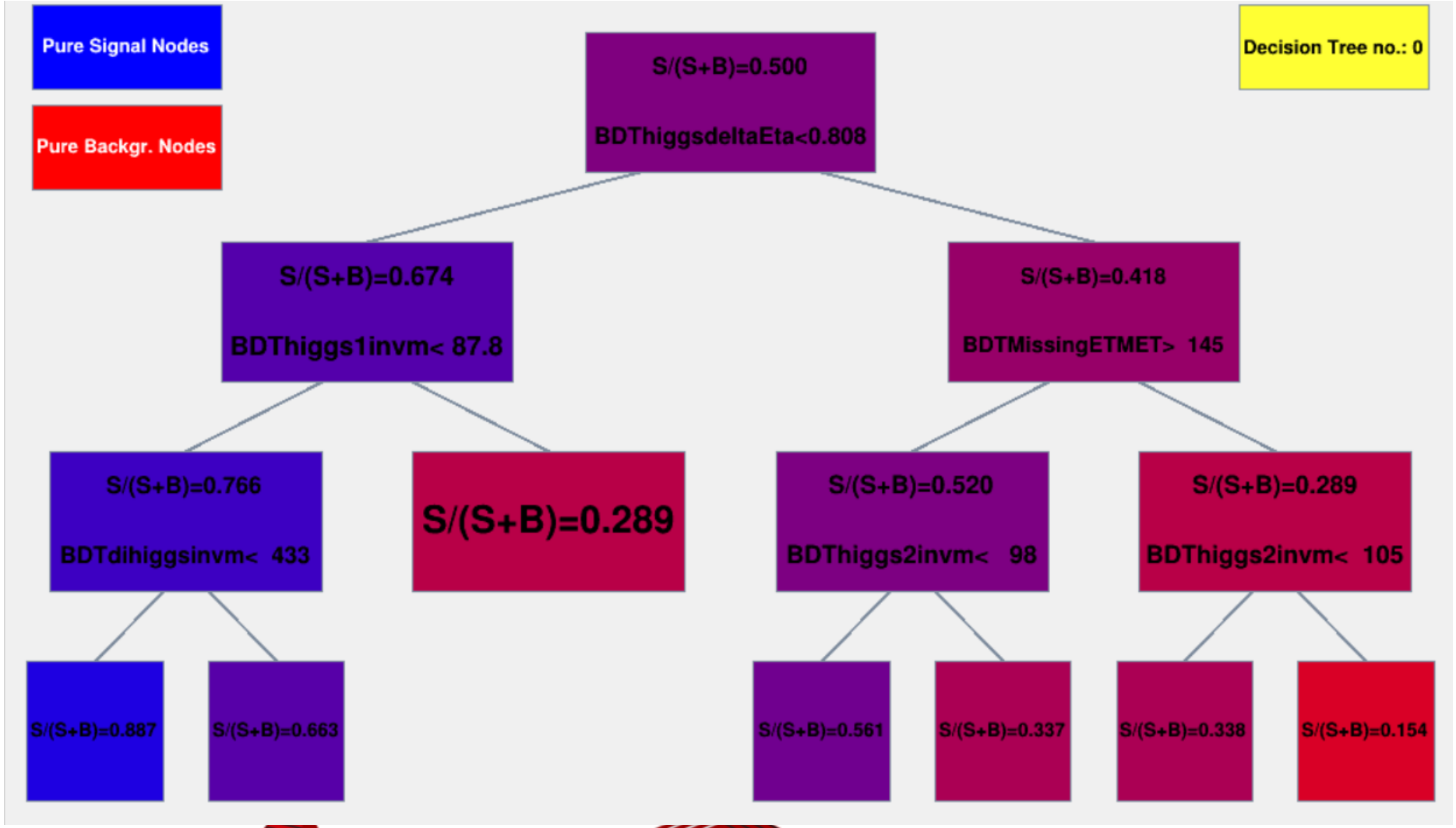

Input variable: BDTdihiggspt
(1/N) dN / 26.8
0.006
0.005
0.004
0.003
0.002
0.001
0
200 400 600 800 1000
BDTdihiggspt
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.1)%

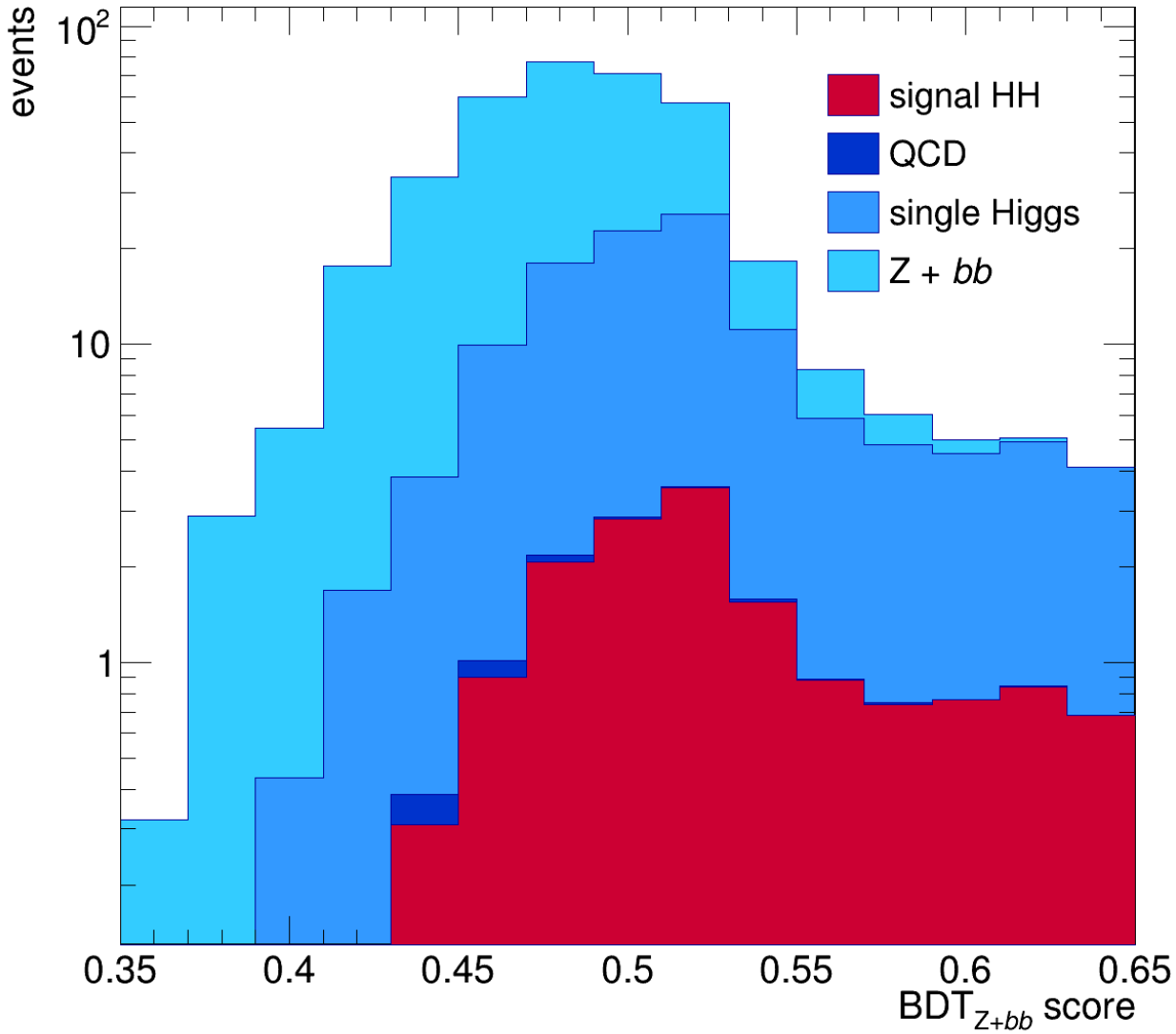

Input variable: BDTdihiggseta
(1/N) dN / 0.275
0.25
0.2
0.15
0.1
0.05
0
−4 −2 0 2 4
BDTdihiggseta
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

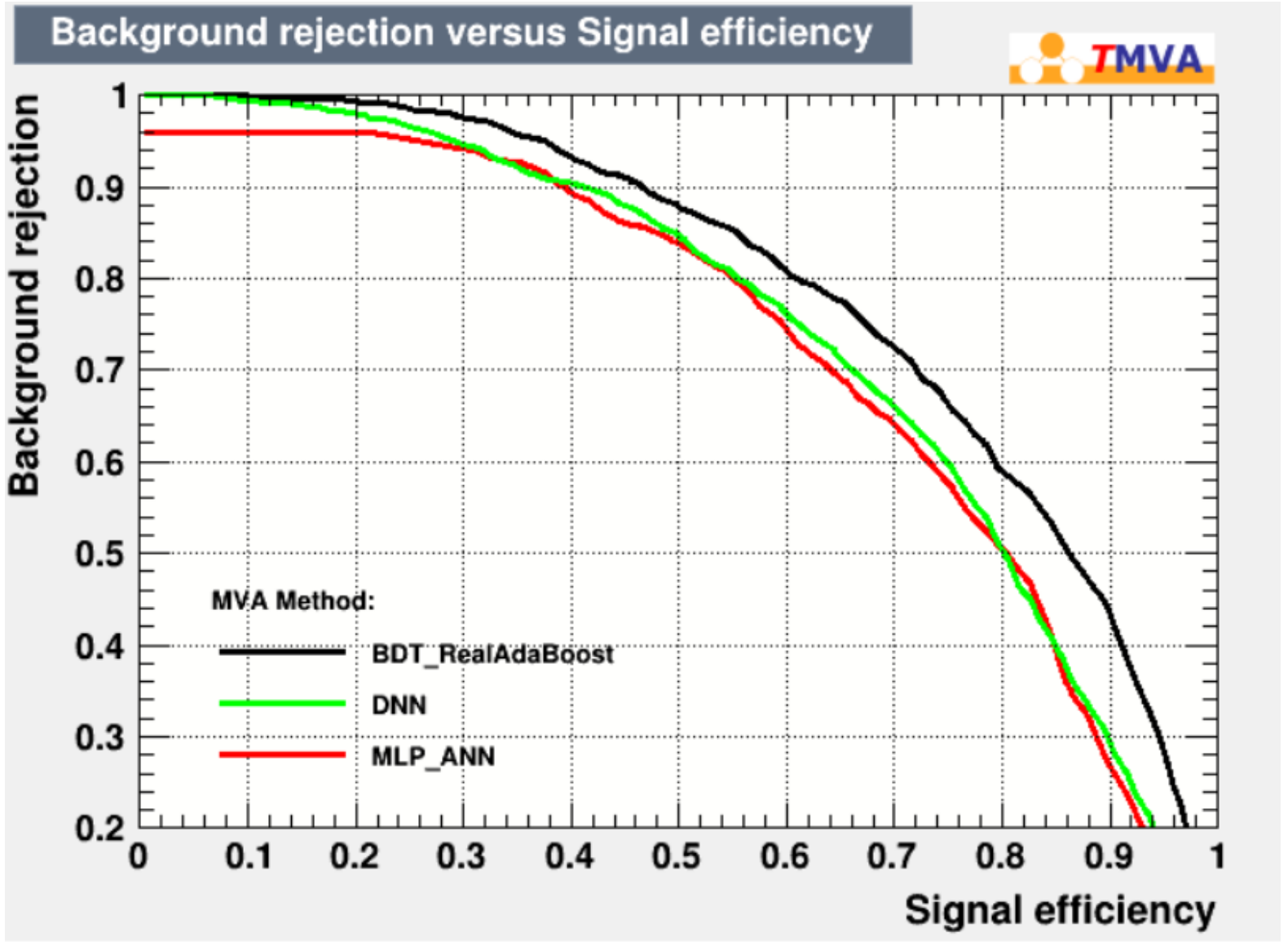

Input variable: BDTdihiggsinvm
(1/N) dN / 46.7
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
200 400 600 800 1000 1200 1400 1600 1800
BDTdihiggsinvm
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%


Cut efficiencies and optimal cut value
Signal efficiency
Background efficiency
Signal purity
Signal efficiency*purity
S/√S+B
Efficiency (Purity)
Significance
1
0.8
0.6
0.4
0.2
0
25
20
15
10
5
0
0.4
0.45
0.5
0.55
0.6
0.65
For 1000 signal and 1000 background
events the maximum S/√S+B is
23.56 when cutting at 0.47
Cut value applied on BDT_RealAdaBoost output


BDTNjets :
BDTjet1pt1 :
BDTjet1pt2 :
BDTjet2pt1 :
BDTjet2pt2 :
BDTjet1eta1 :
BDTjet1eta2 :
BDTjet2eta1 :
BDTjet2eta2 :
BDTjet1phi1 :
BDTjet1phi2 :
BDTjet2phi1 :
BDTjet2phi2 :
BDTMissingETMET :
BDTMissingETEta :
BDTMissingETPhi :
DiHiggsMETDeltaTheta :
BDThiggsdeltaEta :
BDThiggsdeltaPhi :
BDThiggs1pt :
BDThiggs1eta :
BDThiggs1phi :
BDThiggs1invm :
BDThiggs2pt :
BDThiggs2eta :
BDThiggs2phi :
BDThiggs2invm :
BDTdihiggspt :
BDTdihiggseta :
BDTdihiggsphi :
BDTdihiggsinvm :
Bias node :
TMVA
Layer 0
Layer 1
Layer 2
Output layer


Pure Signal Nodes
Pure Backgr. Nodes
Decision Tree no.: 0
S/(S+B)=0.500
BDThiggsdeltaEta<0.808
S/(S+B)=0.674
BDThiggs1invm< 87.8
S/(S+B)=0.418
BDTMissingETMET> 145
S/(S+B)=0.766
BDTdihiggsinvm< 433
S/(S+B)=0.289
S/(S+B)=0.520
BDThiggs2invm< 98
S/(S+B)=0.289
BDThiggs2invm< 105
S/(S+B)=0.887
S/(S+B)=0.663
S/(S+B)=0.561
S/(S+B)=0.337
S/(S+B)=0.338
S/(S+B)=0.154


events
10^2
10
1
signal HH
QCD
single Higgs
Z + bb
0.35
0.4
0.45
0.5
0.55
0.6
0.65
BDT_{Z+bb} score


Background rejection versus Signal efficiency
TMVA
Background rejection
Signal efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
MVA Method:
BDT_RealAdaBoost
DNN
MLP_ANN