Measurement of the top Yukawa coupling at 1.4 TeV using the CLIC SiD Detector

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Introduction

- We consider the production process $e^+e^- \to t\bar{t}H$
  Benchmark process investigated for the ILC DBD at 1 TeV (SiD) (LCD-ANA-2013-001)
- Preliminary studies showed the same number of signal events, but significantly reduced backgrounds for CLIC SiD at 1.4 TeV, no beam polarization, luminosity 1.5 ab^{-1}
- Goal: analyze $t\bar{t}H$ decays to measure the top Yukawa coupling.
- Two final states:
  - 6 jets semi leptonic mode (Sophie Redford)
  - 8 jets fully hadronic mode (Marcelo Vogel)

Signal

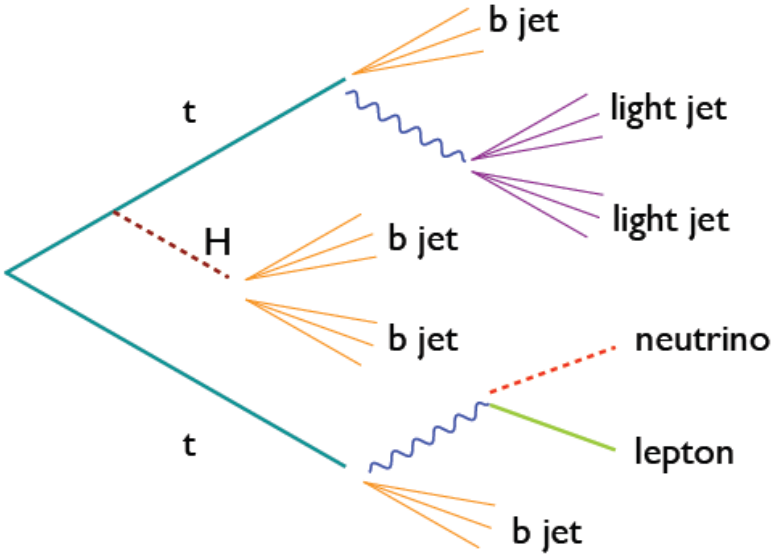
Motivation for the benchmark analysis

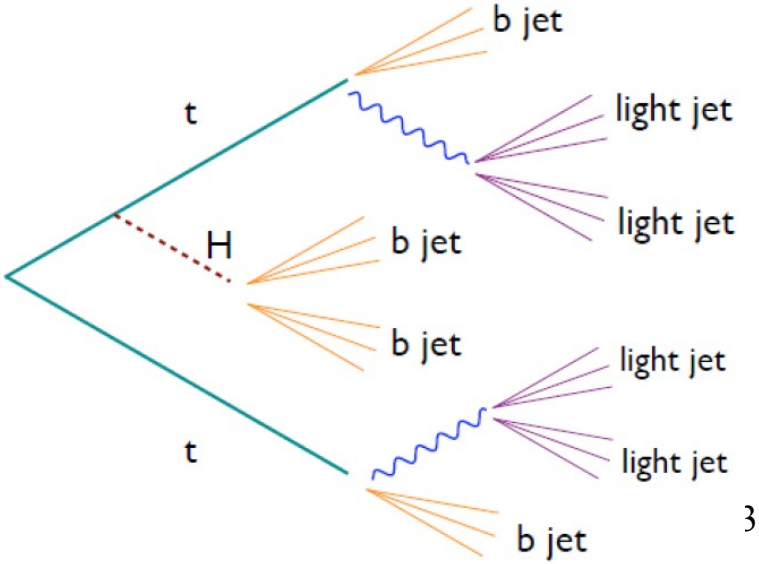
- There is a linear dependence between a Higgs-fermion coupling and the fermion mass
- The top quark, being the heaviest SM particle couples most strongly to the Higgs field
- New physics could induce sizable deviations from SM expectation

6 jets + lepton + nu ← Exclusive samples → 8 jets (lepton veto)

tt->bblvqq, H->bb

tt->bbqqqq, H->bb





Analysis Overview

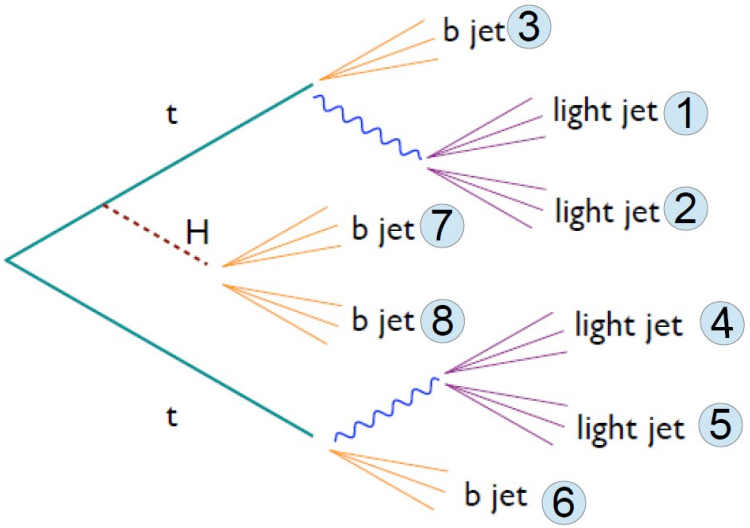
- Selection of Particle Flow Object (PFO) collection and jet radius
  - Jet clustering to 6 or 8 jets
  - Jet matching to W, t and Higgs
  - Choose collection and jet radius that maximizes the resolution
- Analysis of PFO collection
  - Marlin processors: isolated lepton finder, vertex finder, jet clustering and flavor tagging processor.
  - Creation of root trees
  - BDT training and application, Optimization of significance and results

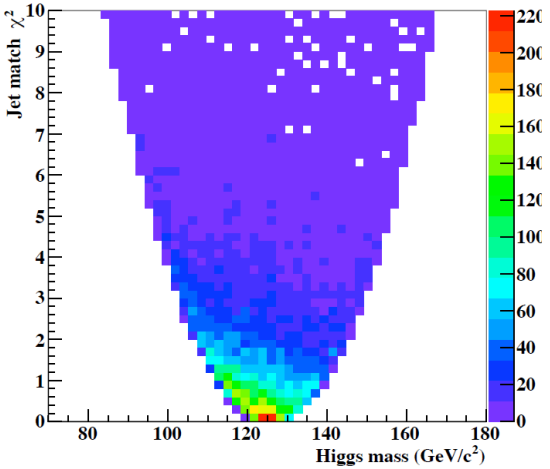
- Selection of PFO collection and jet radius
  - Beam induced backgrounds suppressed with timing cuts. 3 collections available: selected, loose selected and tight selected
  - For each collection:
    - Run FastJet (exclusive Kt algorithm) for different jet radii between 0.5 and 1.5. Merging stops when number of jet = 6 (8)
    - Match jets to W, t and Higgs using chi^2 method
  - Plot reconstructed masses and widths as functions of collection and jet radii
  - Choose Pandora PFO collection and jet radius with the best resolution

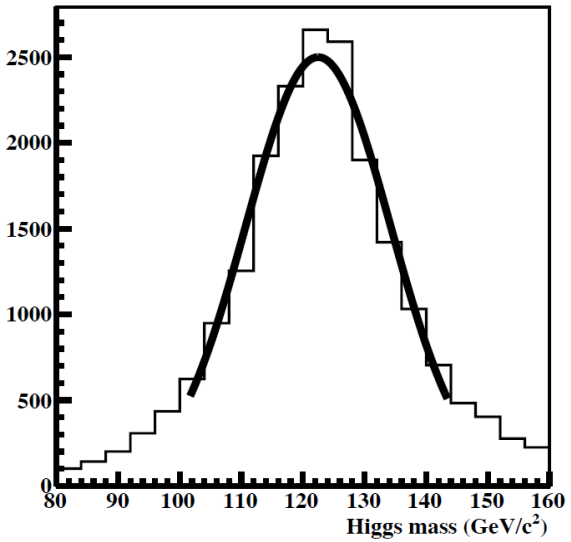
- Jet Matching.
  - For each permutation of the 6 (8) jets, the chi2 is calculated.
  - The configuration that minimizes the chi2 is used to reconstruct the W, top and Higgs

$$\chi^2_{8\,\mathrm{jets}} = \frac{(M_{12}-M_{\mathrm{W}})^2}{\sigma_{\mathrm{W}}^2} + \frac{(M_{123}-M_{\mathrm{t}})^2}{\sigma_{\mathrm{t}}^2} + \frac{(M_{45}-M_{\mathrm{W}})^2}{\sigma_{\mathrm{W}}^2} + \frac{(M_{456}-M_{\mathrm{t}})^2}{\sigma_{\mathrm{t}}^2} + \frac{(M_{78}-M_{\mathrm{H}})^2}{\sigma_{\mathrm{H}}^2}$$

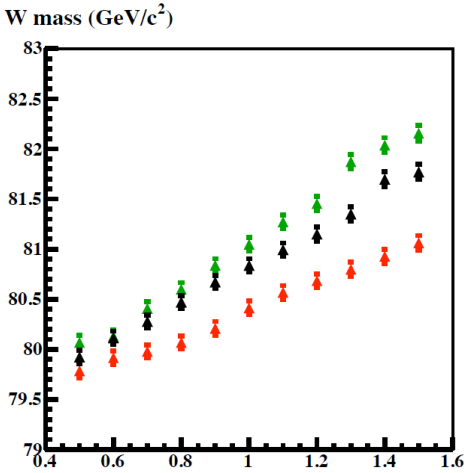
M_w, M_t, M_H, σ_W, σ_t and σ_H obtained by matching PFOs in jets to MC quarks

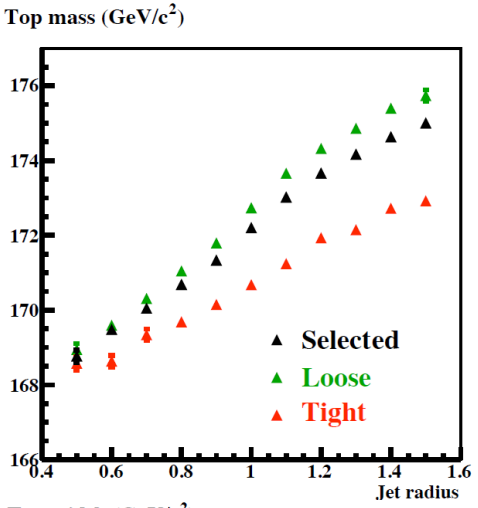


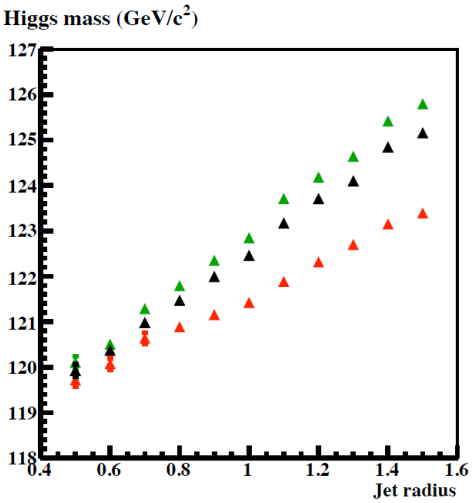


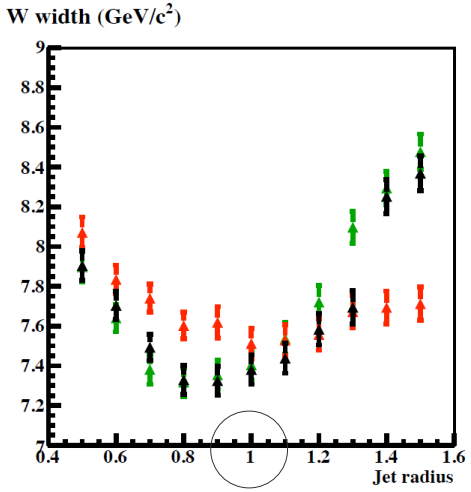


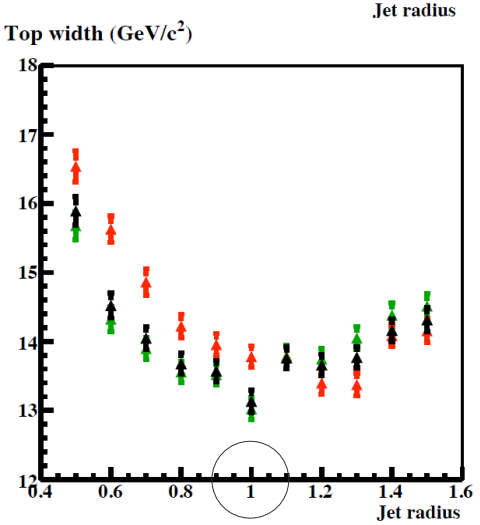
- Resolution as a function of PFO collection and jet radius
  - Measure width of W, top and Higgs obtained from the minimization of chi^2
  - Repeat for each PFO collection and for different jet radii between 0.5 and 1.5

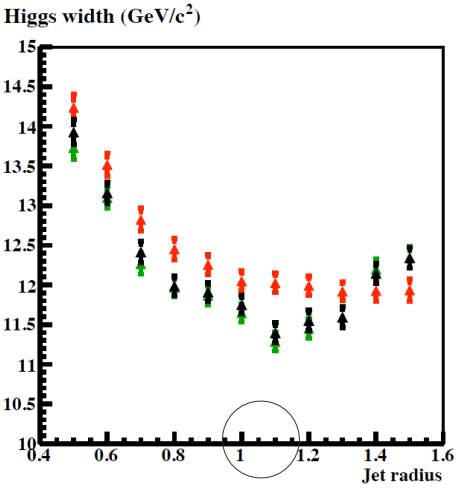






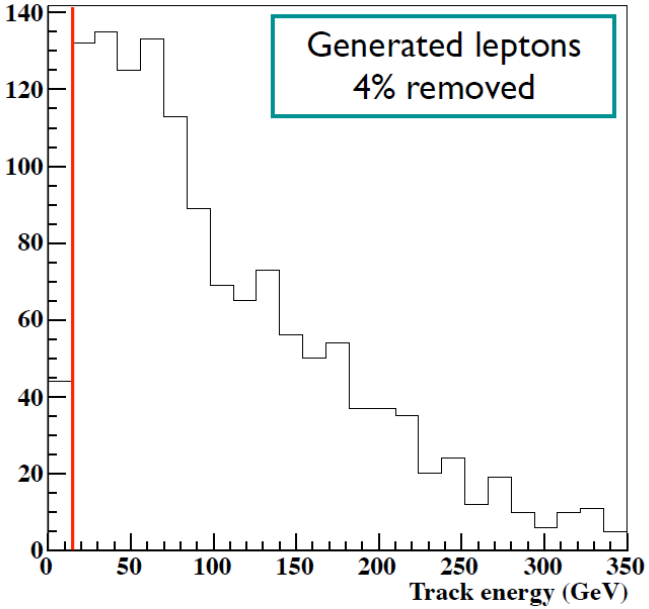


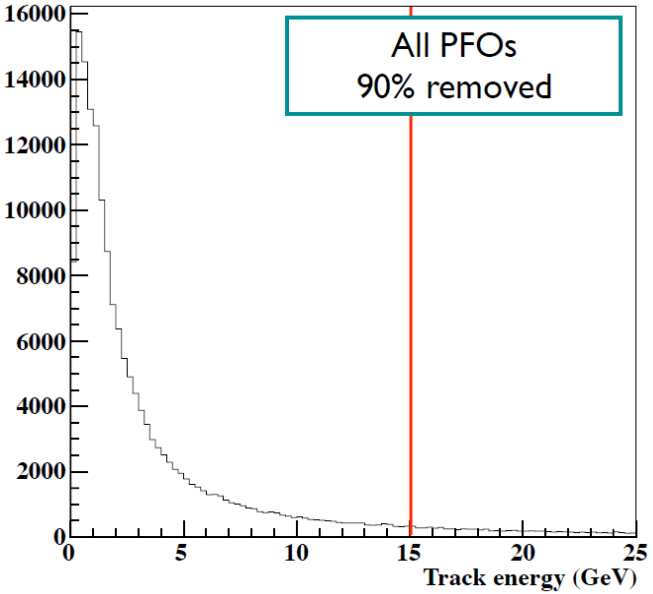


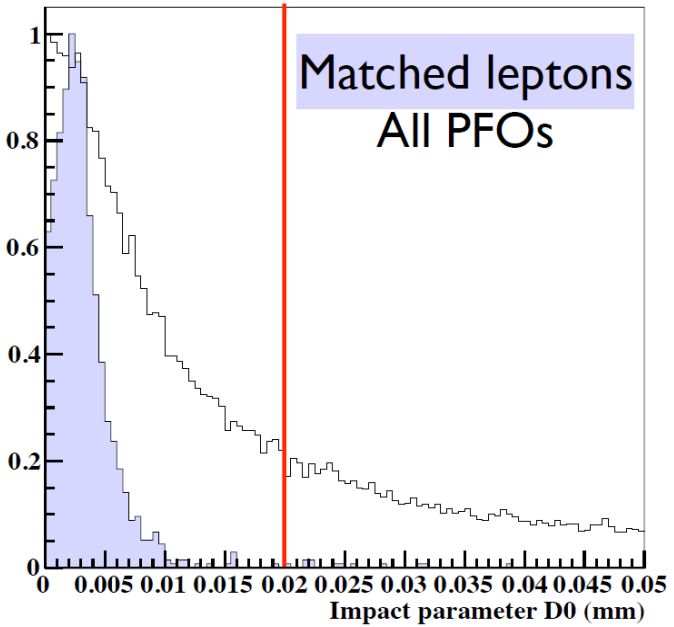


- Analyze the PFO collection
  - LCSim: To include missing sub-detector track hit numbers and calorimeter energy
  - Marlin processors
    - Isolated lepton finder (e/mu). Optimized by Sophie. IP, isolation, track energy and energy fraction
    - FastJet (hadron collider KT). Input has no isolated leptons, output excludes PFOs in beam jets
    - Vertex finder (Lcfiplus): primary and secondary vertices
    - Training of BDTs for b-tags is done using 6 jet final states (Philipp)
    - Jet clustering and flavor tagging (Lcfiplus)
    - Creation of root trees for kinematics
    - MVA selection and maximization of significance

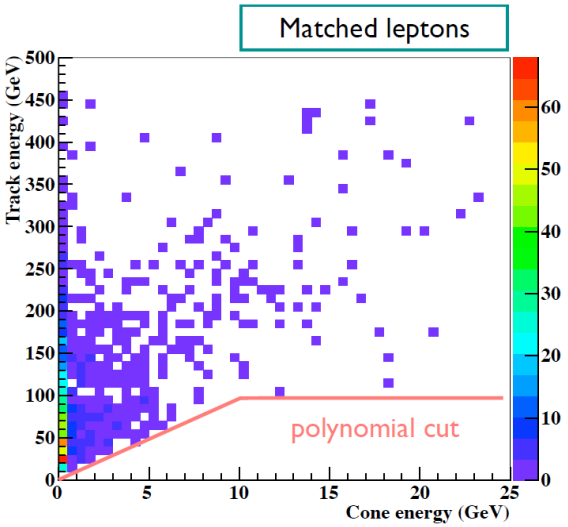
Lepton identification

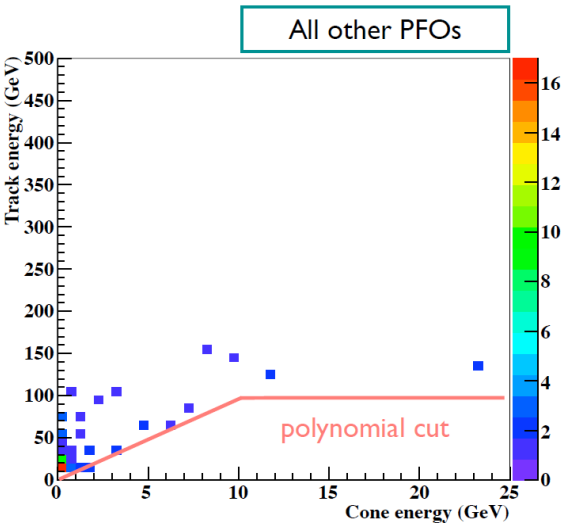


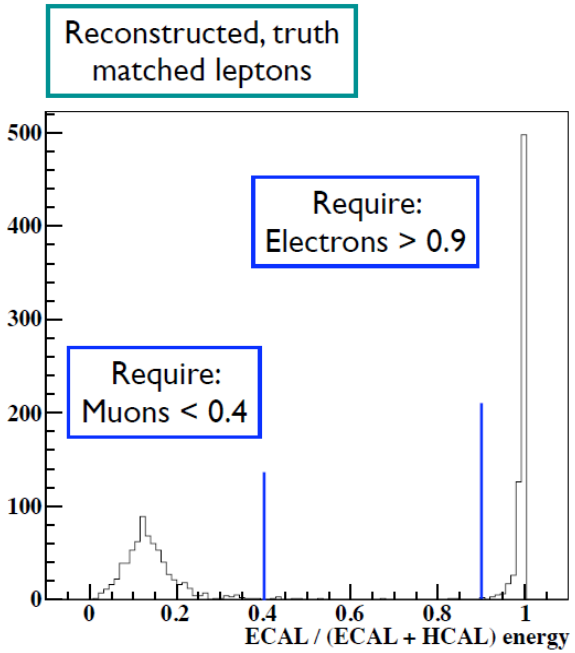


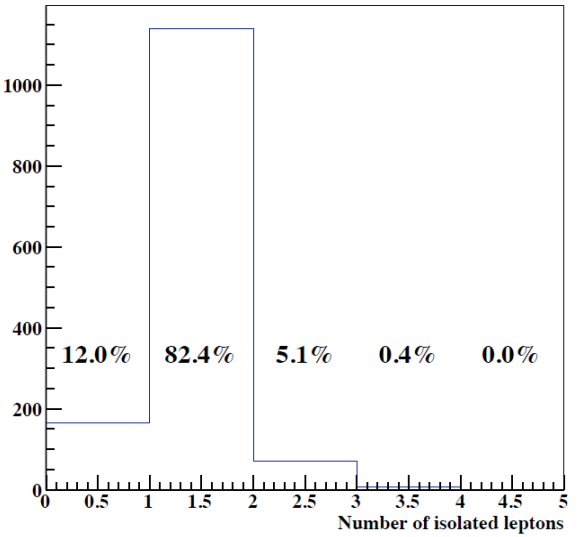


Lepton Isolation and PID information









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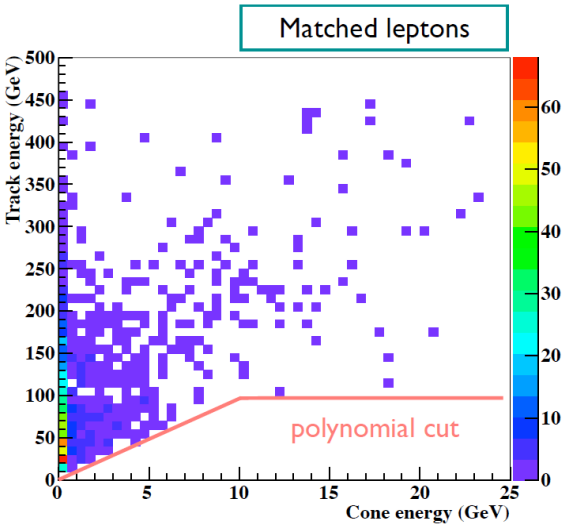
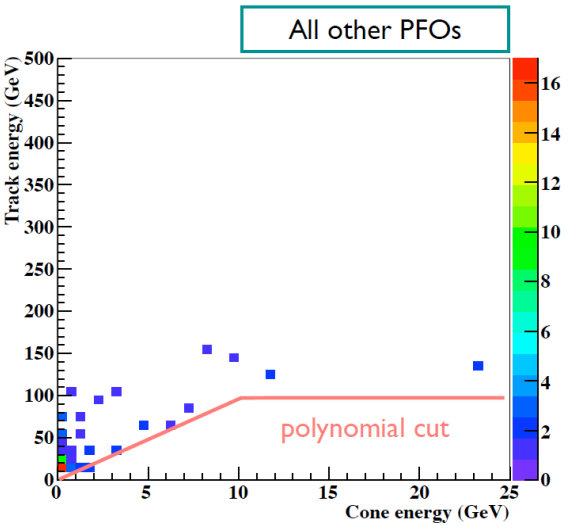
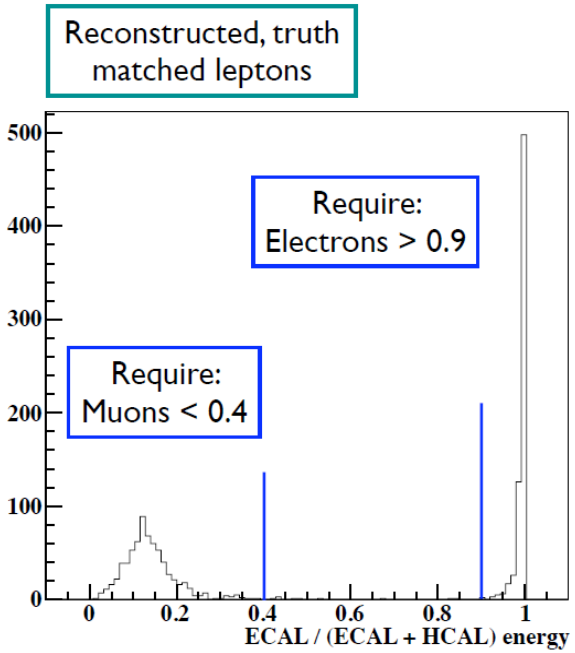
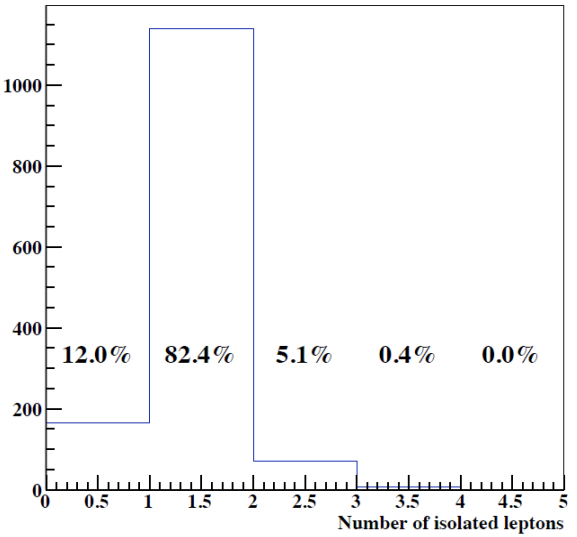
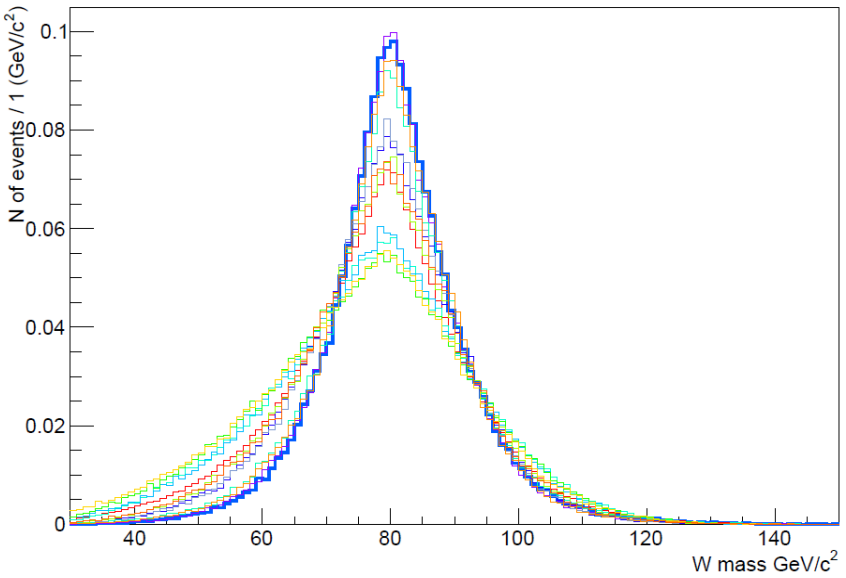


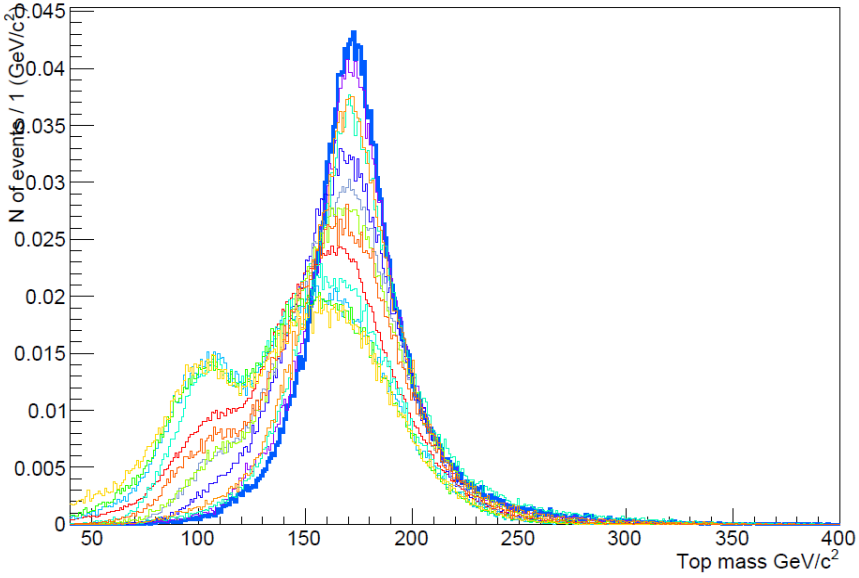


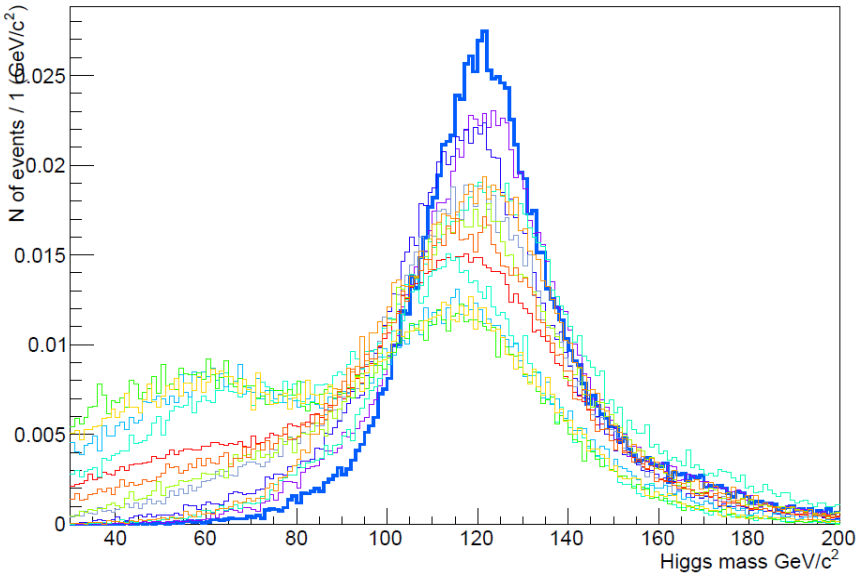




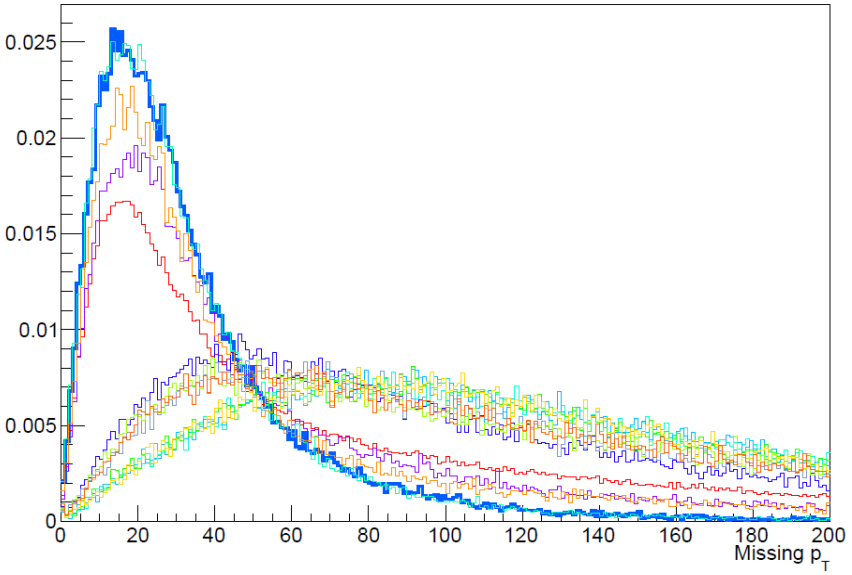
Variables: Masses

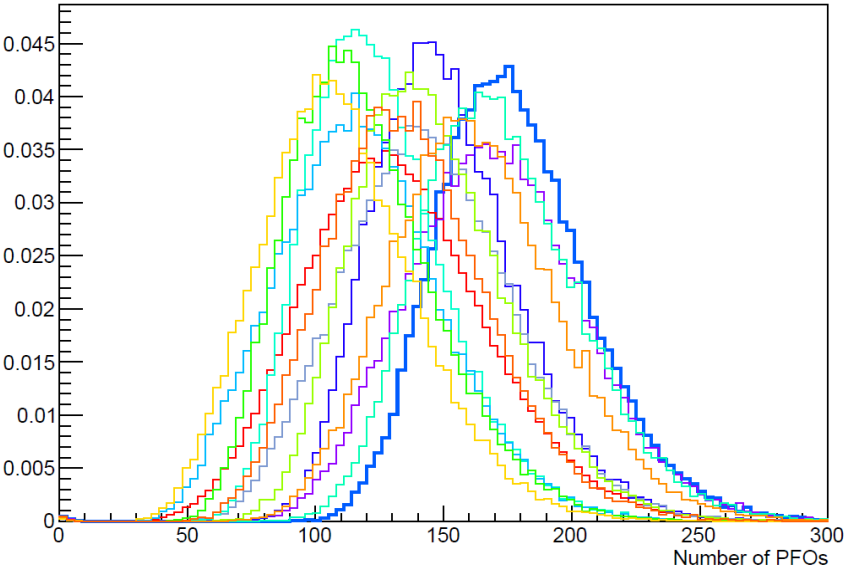


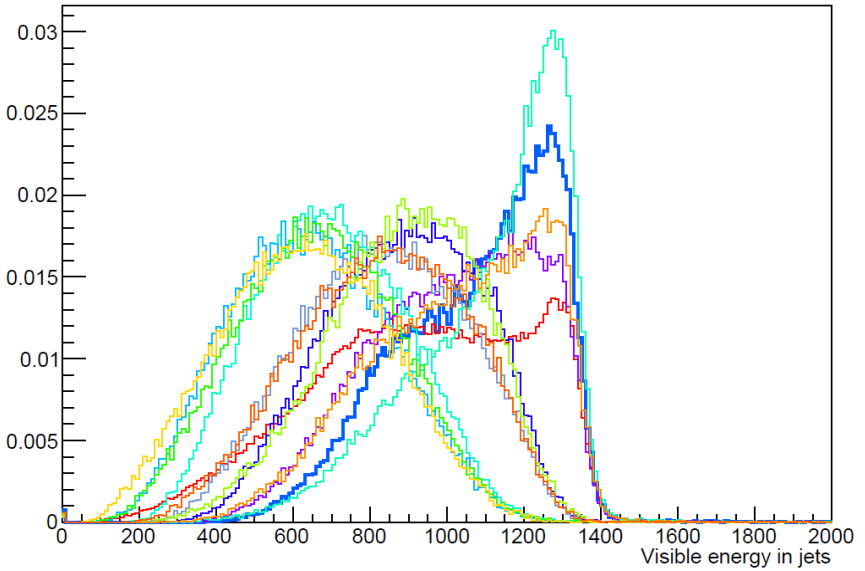




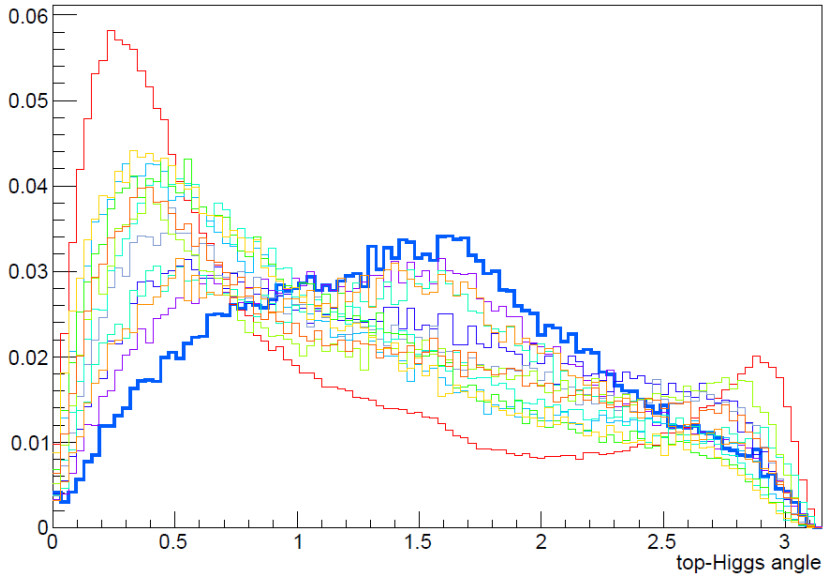
Variables: event quantities

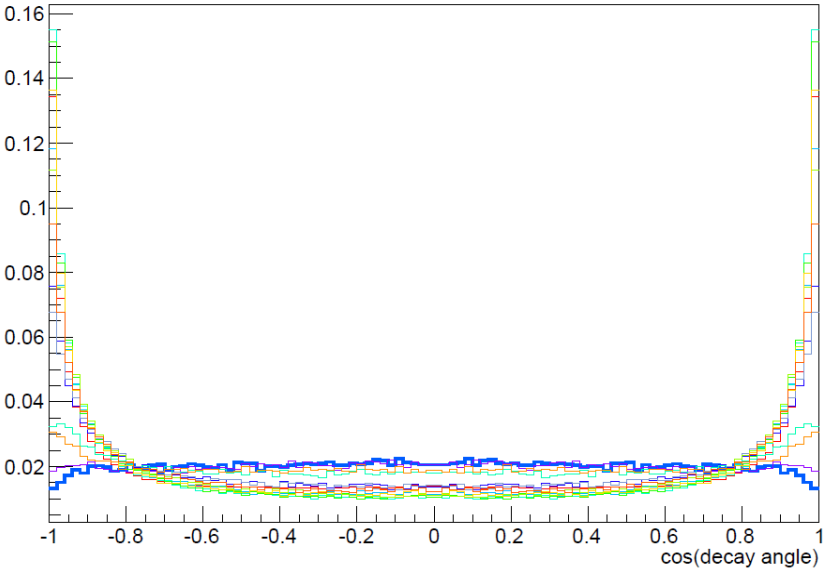




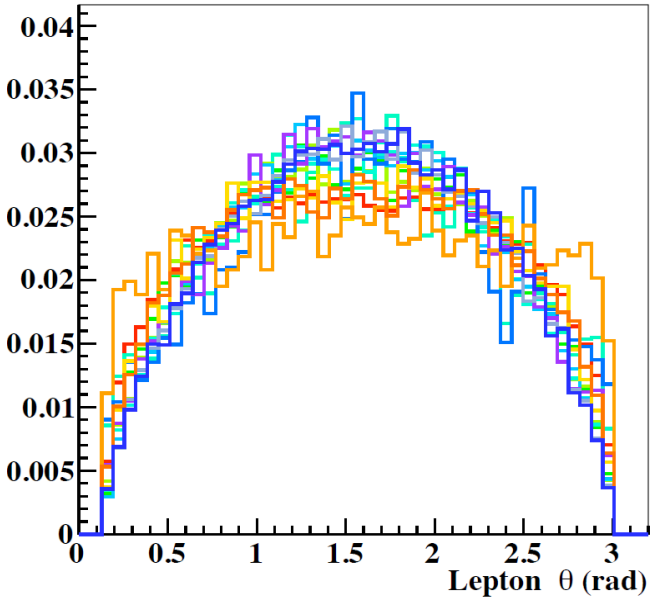


Variables: angles

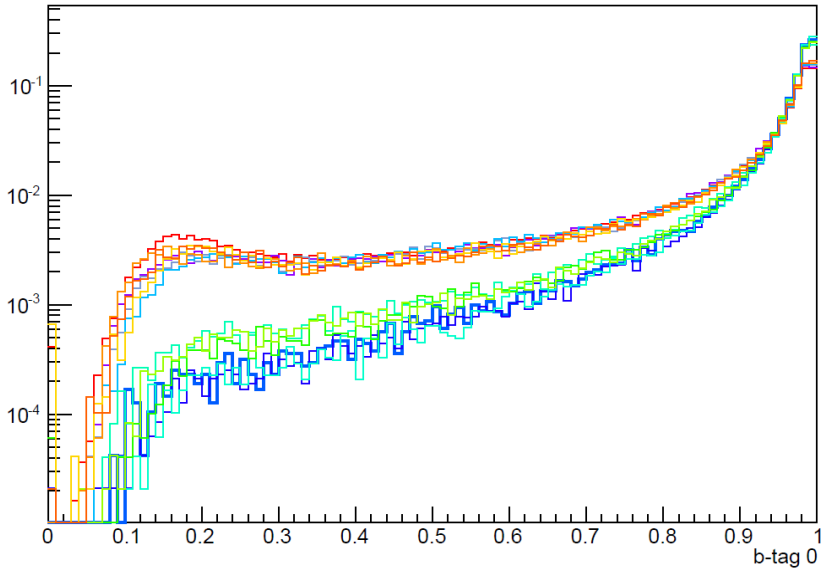


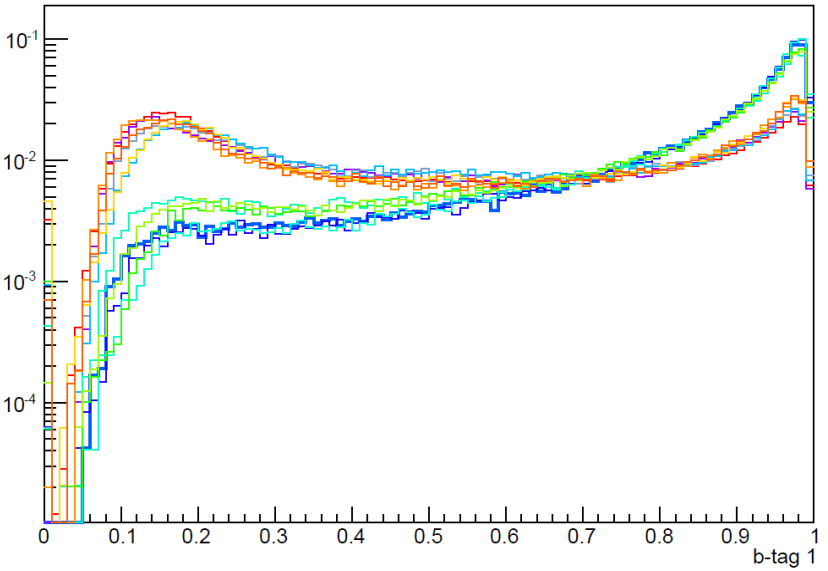


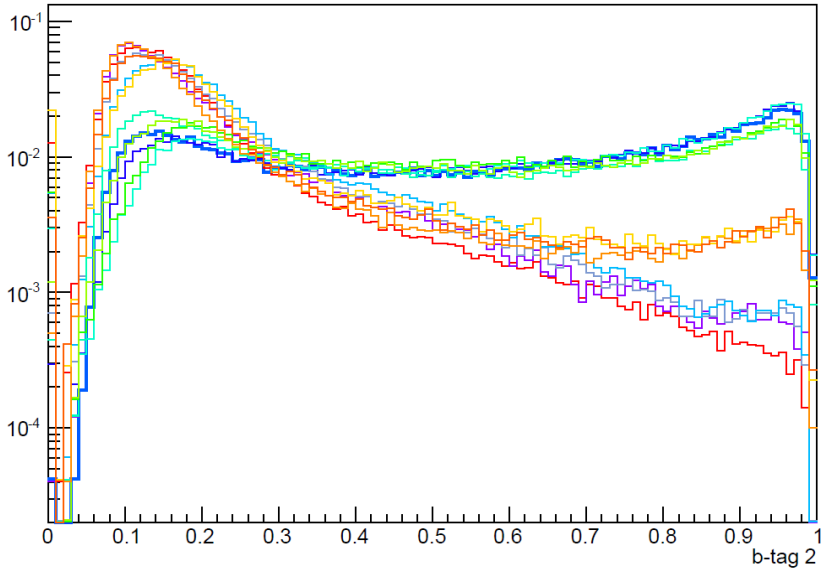
ttH ln4q Hbb
tt
ttbb 2l2nbb all
ttbb 6q all
ttbb ln4q all
ttH 2l2nbb Hbb
ttH 2l2nbb Hnonbb
ttH 6q hbb
ttH 6q Hnonbb
ttH ln4q Hnonbb
ttZ 2l2nbb all
ttZ 6q all
ttZ ln4q all

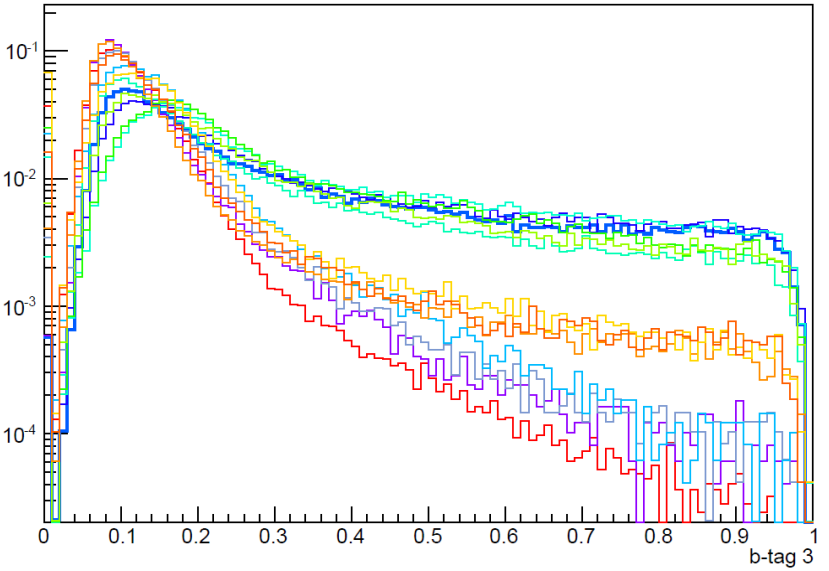


Variables: b-tags

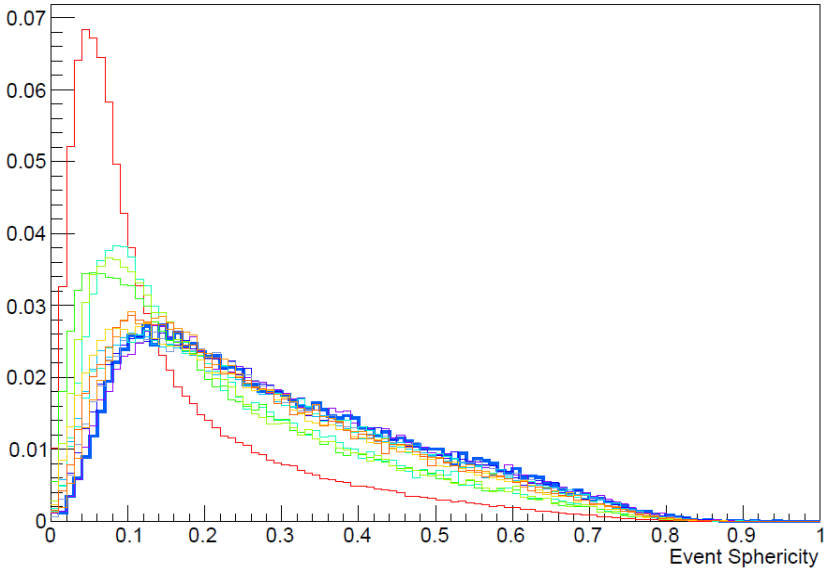


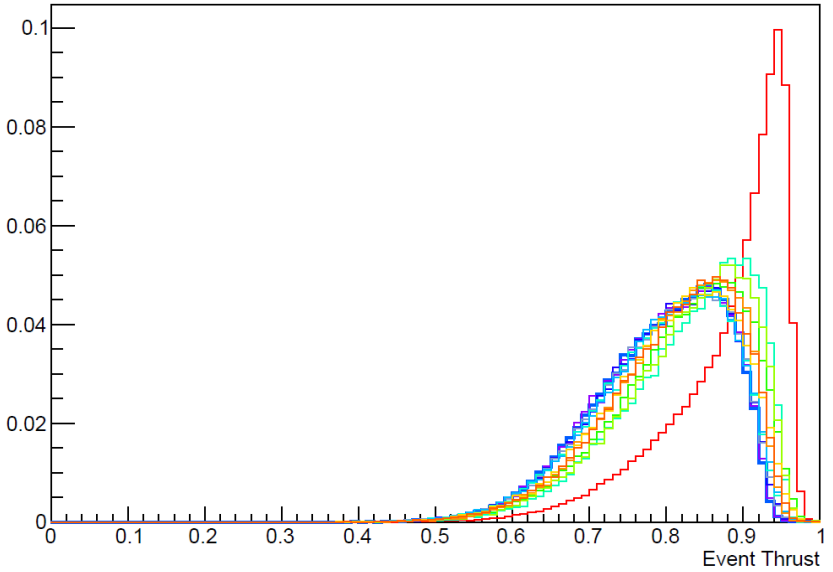




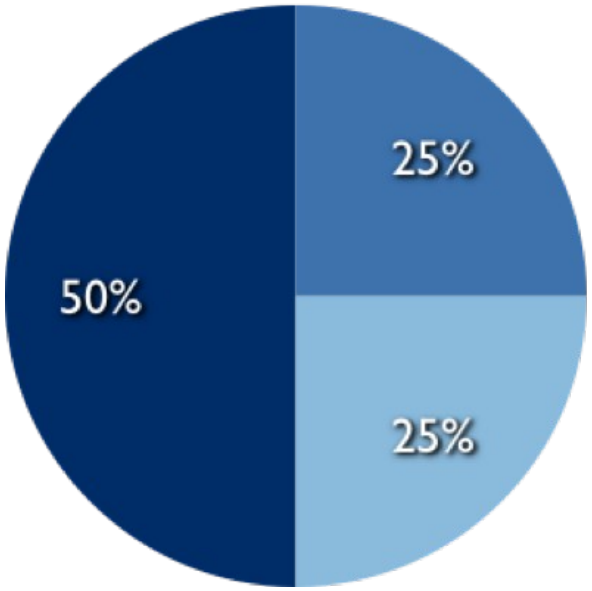


Variables: event shapes

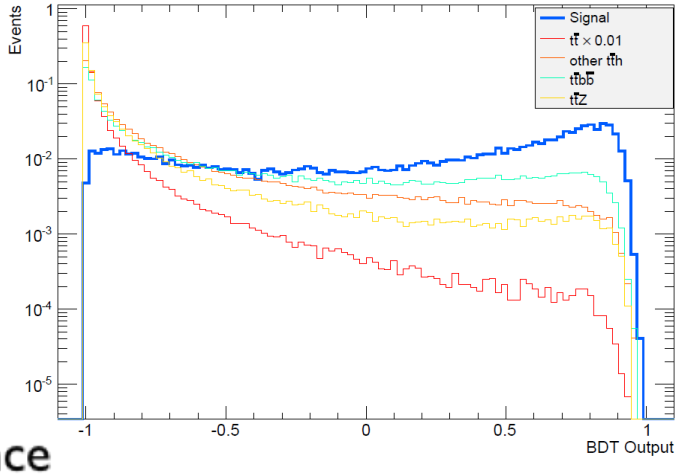




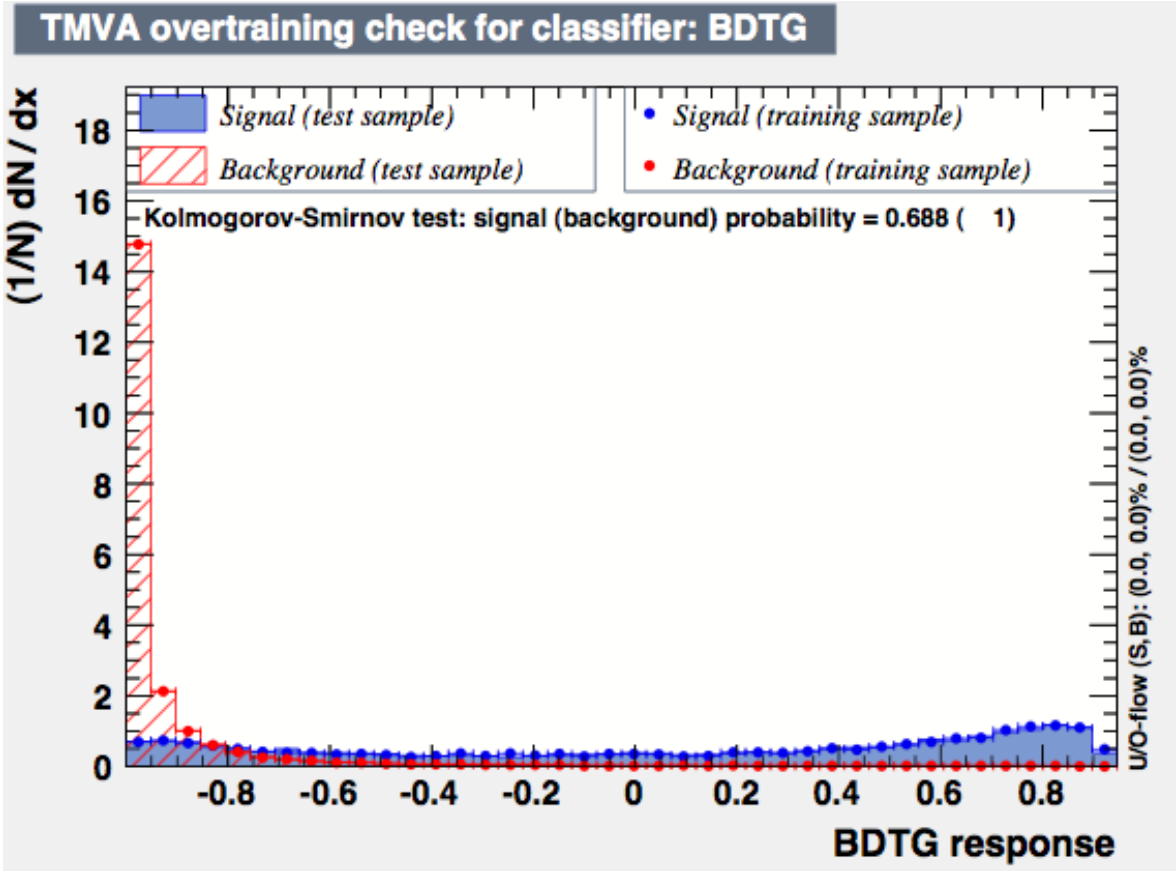
TMVA



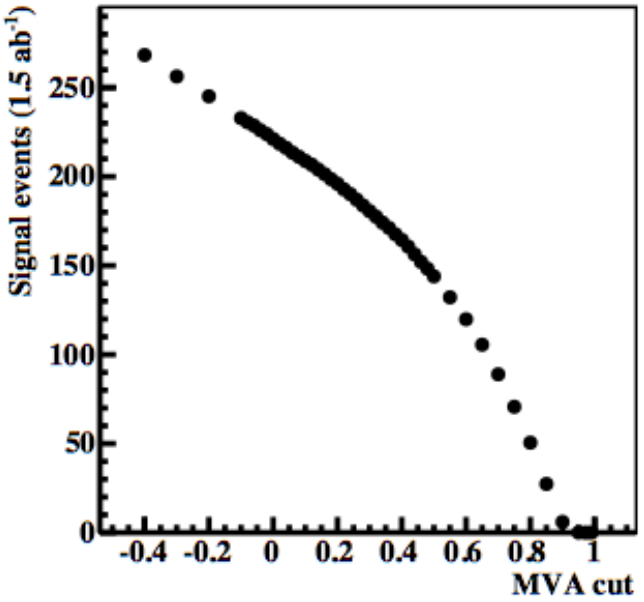
- Train in TMVA
- Test in TMVA
- 'Data' to evaluate significance

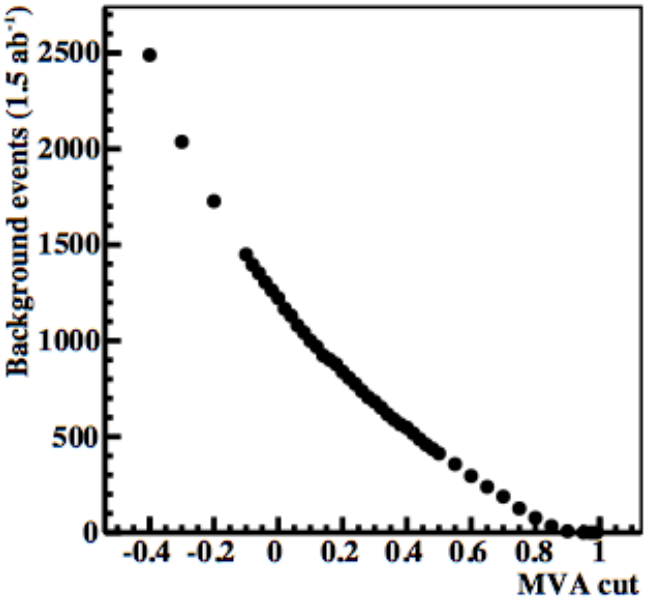


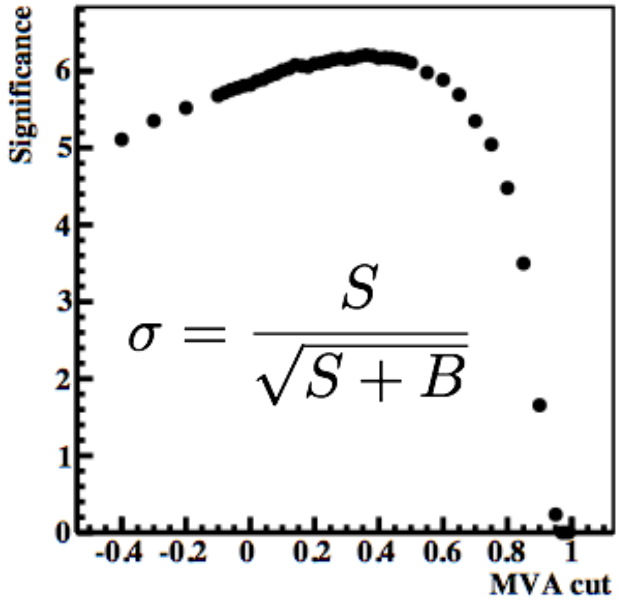
- Use BDT with gradient boost
- Trained on 20 variables
- 'Default' options
- No sign of overtraining



Significance optimization







- MVA selection chosen to maximize the significance
- MVA response > 0.36 gives significance of 6.2 (6 jets)

Yields per process after flavor tagging, BDT training and application. Cut at BDT score = 0.36 (0.32)

Process	Cross section (fb)	Events in 1.5 ab^{-1}	Pass BDT (6 jets)	Efficiency (%)	Pass BDT (8 jets)	Efficiency (%)
$t\bar{t}H$, 6 jets, $H \to b\bar{b}$	0.431	647	10	1.54	318	49.1
$t\bar{t}H$, 4 jets, $H \to b\bar{b}$	0.415	623	171	27.4	62	9.93
$t\bar{t}H$, 2 jets, $H \to b\bar{b}$	0.1	150	22	14.7	2	1.27
$t\bar{t}H$, 6 jets, H not $b\bar{b}$	0.315	473	2	0.423	17	3.63
$t\bar{t}H$, 4 jets, H not $b\bar{b}$	0.303	455	7	1.54	3	0.621
$t\bar{t}H$, 2 jets, H not $b\bar{b}$	0.073	110	1	0.909	1	0.101
$t\bar{t}b\bar{b}$, 6 jets	0.549	824	7	0.850	244	29.6
$t\bar{t}b\bar{b}$, 4 jets	0.529	794	124	15.6	42	5.31
$t\bar{t}b\bar{b}$, 2 jets	0.127	191	17	8.90	2	0.783
$t\bar{t}Z$, 6 jets	1.895	2843	6	0.211	217	7.64
$t\bar{t}Z$, 4 jets	1.825	2738	104	3.80	36	1.33
$t\bar{t}Z$, 2 jets	0.439	659	14	2.12	1	0.201
$t\bar{t}$	135.8	2037	274	0.134	802	0.394

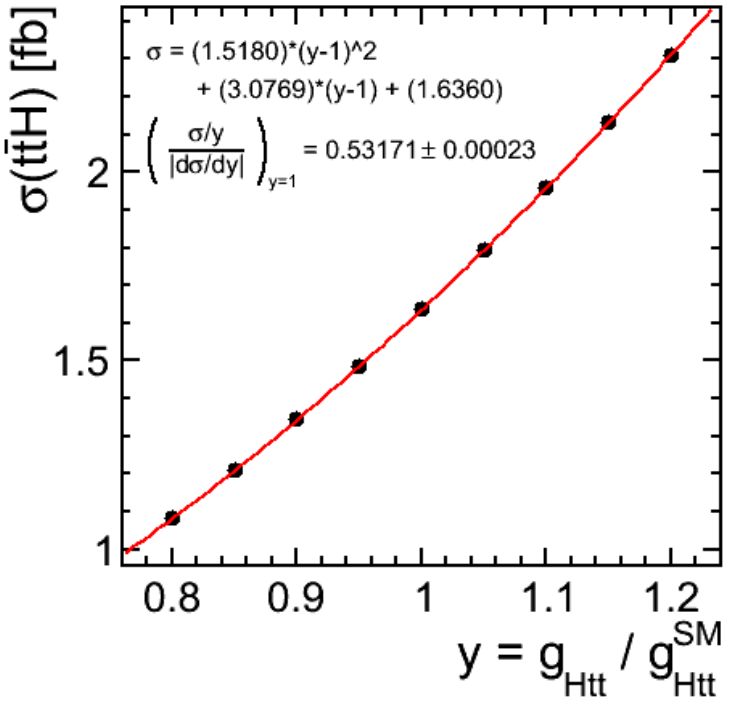
$t\bar{t}h$ Combination

- The signal cross section (all tth samples) can be measured with a precision of:
  - $\Delta\sigma/\sigma$ = 12.9% in the 6 jet final state
  - $\Delta\sigma/\sigma$ = 10.4% in the 8 jet final state
  - $\Delta\sigma/\sigma$ (combined) = 8.1%. Independent samples

- Linear relation between the uncertainty in the cross section and the uncertainty in the top Yukawa coupling

$\Delta g_{ttH}/g_{ttH} = 0.53\ \Delta\sigma/\sigma$

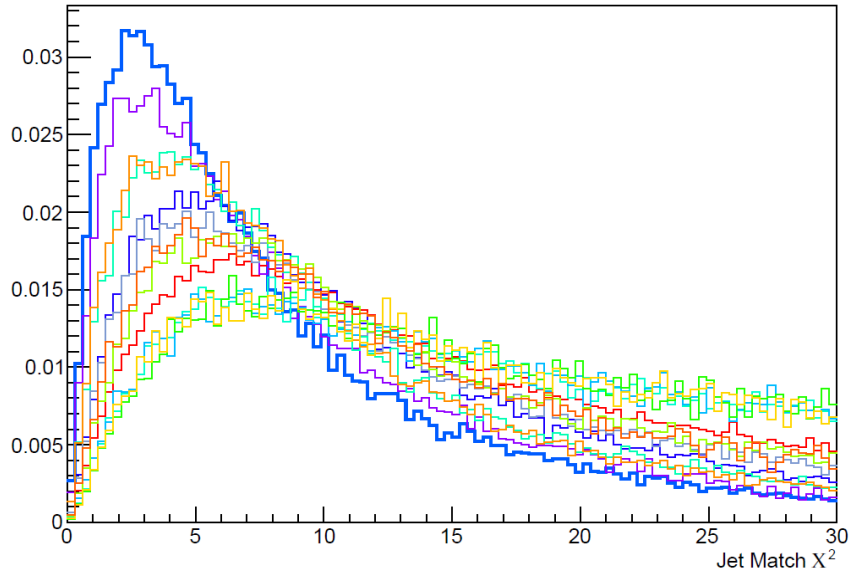
$\Delta g_{ttH}/g_{ttH}$ = 4.3%

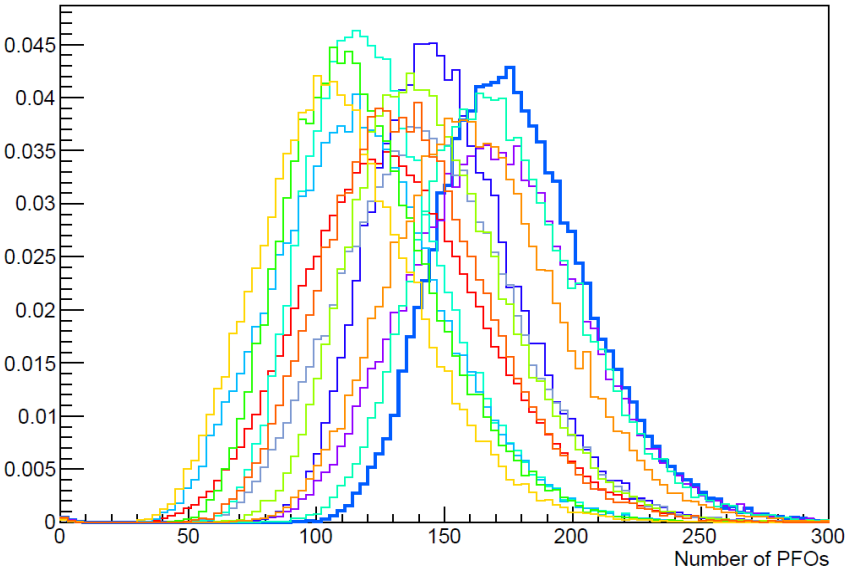


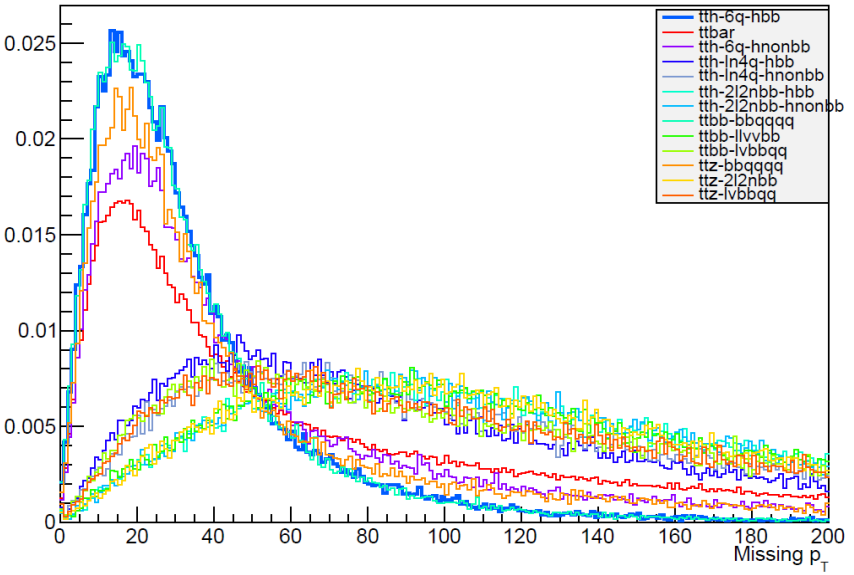
- Summary
  - We achieved a similar reconstructive performance as in the ILC 1 TeV analysis
  - Preliminary results show a higher precision on the measurement of the top Yukawa coupling. The combined uncertainty $\Delta g_{ttH}/g_{ttH} = 4.3\%$ compares to that obtained in the ILC analysis at 1 TeV measured at 4.5%

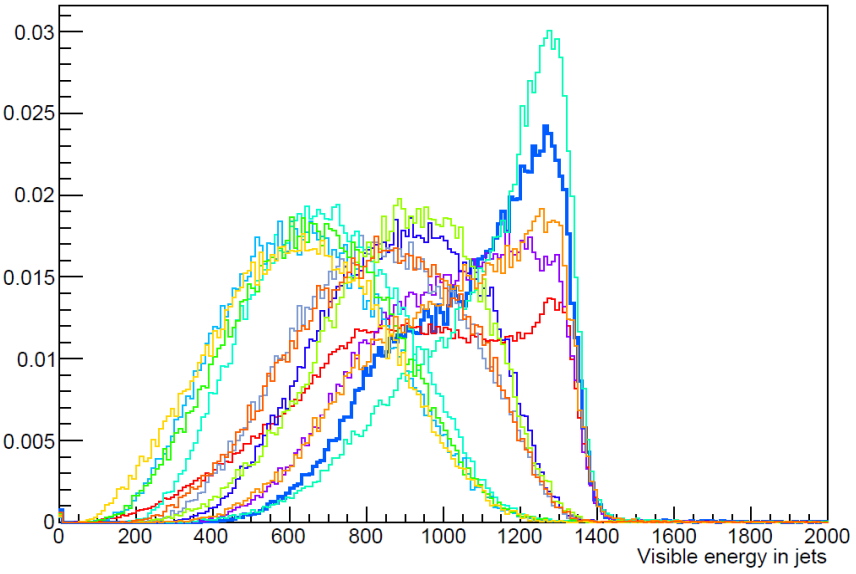
- Future steps
  - We expect an improvement in signal significance by optimizing selection further.
  - We plan to include tau leptons. Sophie working on optimization of tau lepton finder

Backup


Jet Match X^2

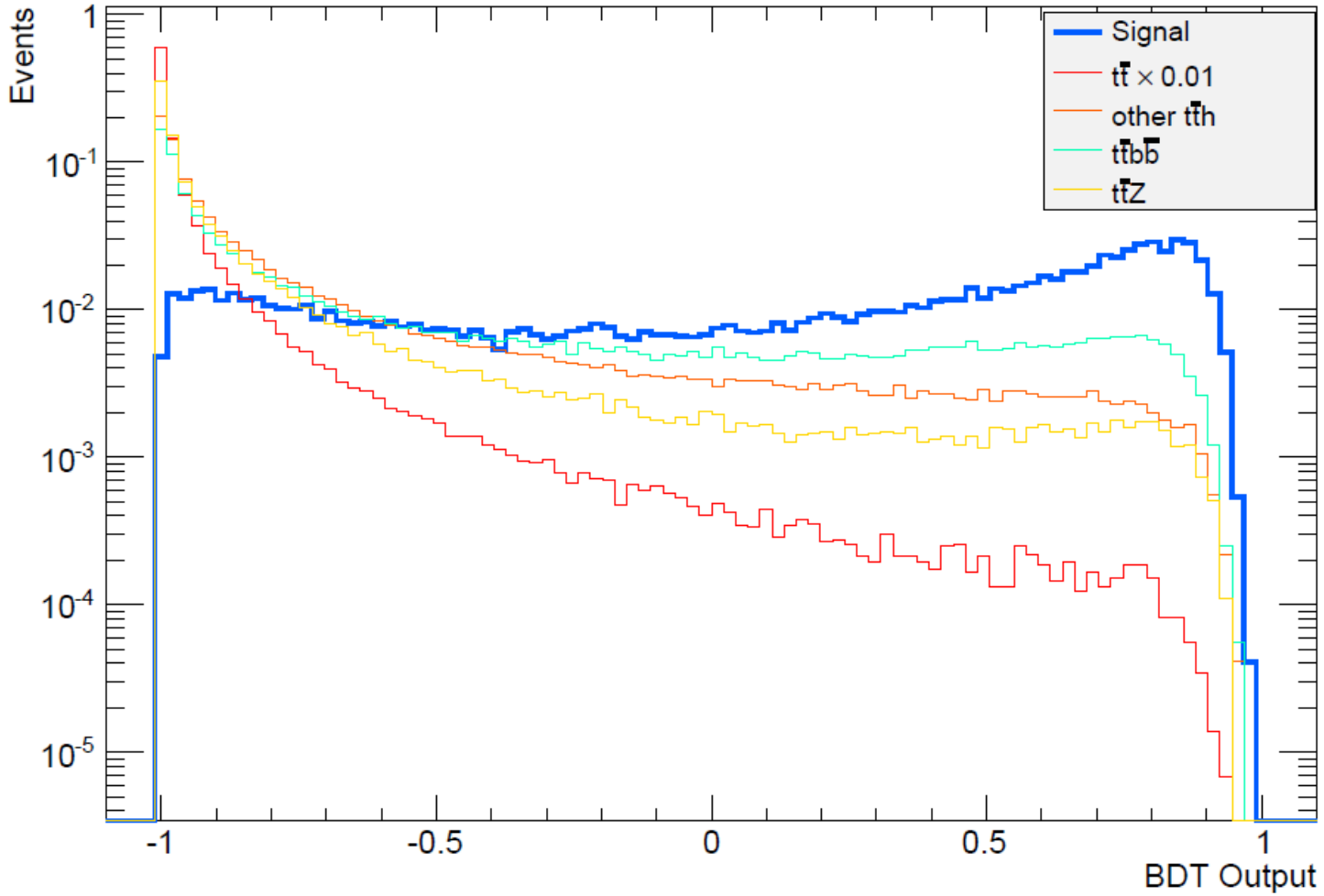

Number of PFOs


tth-6q-hbb
ttbar
tth-6q-hnonbb
tth-ln4q-hbb
tth-ln4q-hnonbb
tth-2l2nbb-hbb
tth-2l2nbb-hnonbb
ttbb-bbqqqq
ttbb-llvvbb
ttbb-lvbbqq
ttz-bbqqqq
ttz-2l2nbb
ttz-lvbbqq
Missing p$_T$


Visible energy in jets

TMVA

- BDTG response per sample



Tau events

- Sometimes the W decays to a tau
- Sometimes (35%) the tau decays leptonically
- We could reconstruct the e/mu as the isolated lepton