Higgs Detection Sensitivity from GGF H → WW

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Outline

- Introduction
- Monte Carlo Samples for H→WW study
- Cut-based analysis
- Boosted Decision Trees analysis
- H → WW detection sensitivity
- Summary

Introduction

- This study is part of the effort at the University of Michigan to contribute to the HG4 CSC note.
- Our studies have used both cut-based analysis and Boosted Decision Trees technique. Major results are summarized in **[H. Yang et.al., ATL-COM-PHYS-2008-023]**
- This talk will focus on studies using the H→ WW events from gluon-gluon-fusion process.
- UM contributors for this work

  Hai-Jun Yang, Tiesheng Dai, Dan Levin, Xuefei Li, Alan Wilson, Zhengguo Zhao, Bing Zhou

MC Higgs Signal Used in Study

(ATLAS software rel. v12)

- Pythia Generator (Gluon-Gluon Fusion)

$H \rightarrow WW \rightarrow e\nu e\nu,\ \mu\nu\mu\nu,\ e\nu\mu\nu$

GGF $H \rightarrow WW$	Dataset #	MC Events	$\sigma \times$ BR (fb)
M_H = 150 GeV	3010	97400	767
M_H = 165 GeV	3025	96200	866
M_H = 170 GeV	5329	167200	825
M_H = 175 GeV	3035	193450	770
M_H = 180 GeV	3040	96250	716

- There is no official PYTHIA ggF $H \rightarrow WW$ sample with v12.0.6.4 up
- Above Higgs samples were produced at UM using jobOptions similar to official jobOption DS5320 (with diff. M_H and separate the ggF and VBF production)
- UM Pythia Higgs samples were compared to Higgs dataset 5320 by separating the ggF and the VBF events, they are in good agreement.
- UM samples are available at BNL Tier-1 center.

MC Backgrounds Used in Study

(SM samples were used for ATLAS diboson CSC note)

Backgrounds	Dataset #	MC Events	$\sigma \times$ BR (fb)
qq → WW	2821 – 2829	210 K	12503
gg → WW	5921 – 5929	370 K	648
ttbar	5200	529 K	4.6E5
WZ	5941, 5971	281 K	688
W + X:			5.75E7
W→ln	5250 – 5255	5.25 M	5.62E7
W+Jets(E>80)	4288, 4289	595 K	1.3E6
Z + X:			6.9E6
ZZ	6356, 5980	181 K	84
Drell-Yan	4295 - 4297	10.5 M	6.8E6
Z+Jets(E>80)	4293, 4294	597 K	52800
Zbb	5175 – 5177	200 K	48720

Event Pre-selection

for H→ WW→ $l\nu l\nu$

- Two leptons with opposite charges; each lepton with P_T > 10 GeV
- Missing E_T > 15 GeV
- Events must pass one of lepton trigger requirements: 2E10, 2MU6, E25I, MU20
- Physics objects:
  - Electron ID based on likelihood ratio > 0.6
  - Muon ID based on Staco algorithm
  - Jet class: C4TopoJet (E_T > 20 GeV)

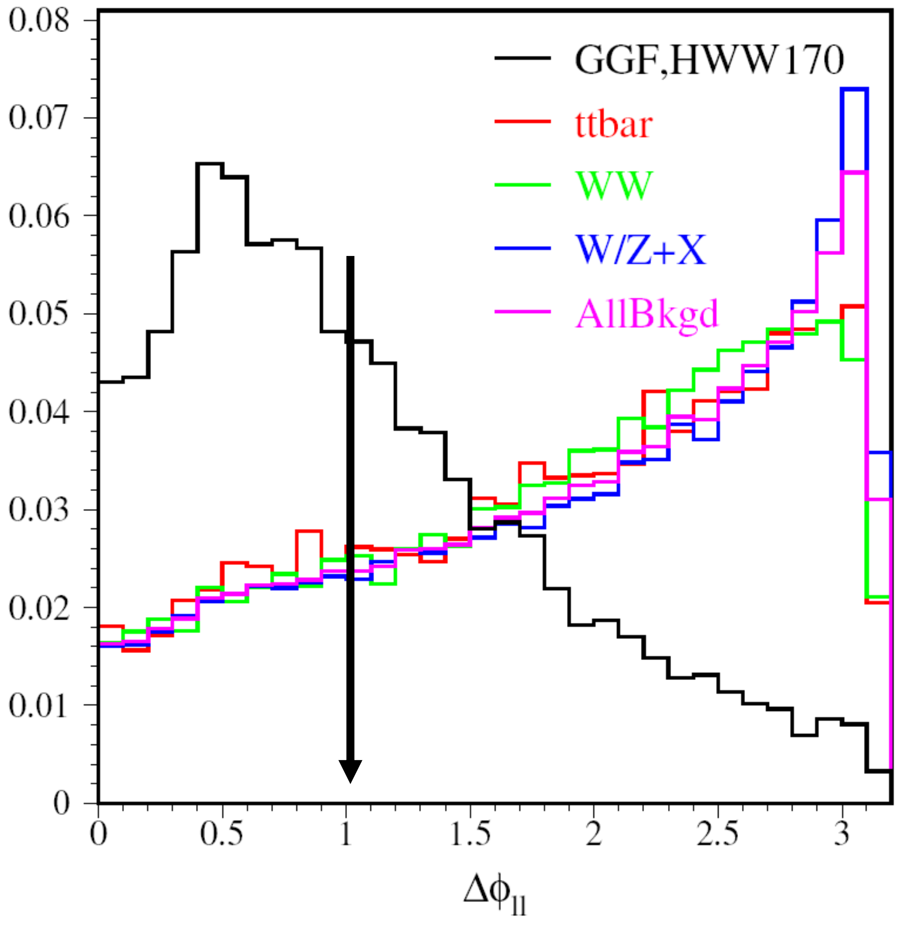
Detection Sensitivity Studies
Based on Pre-selected Events

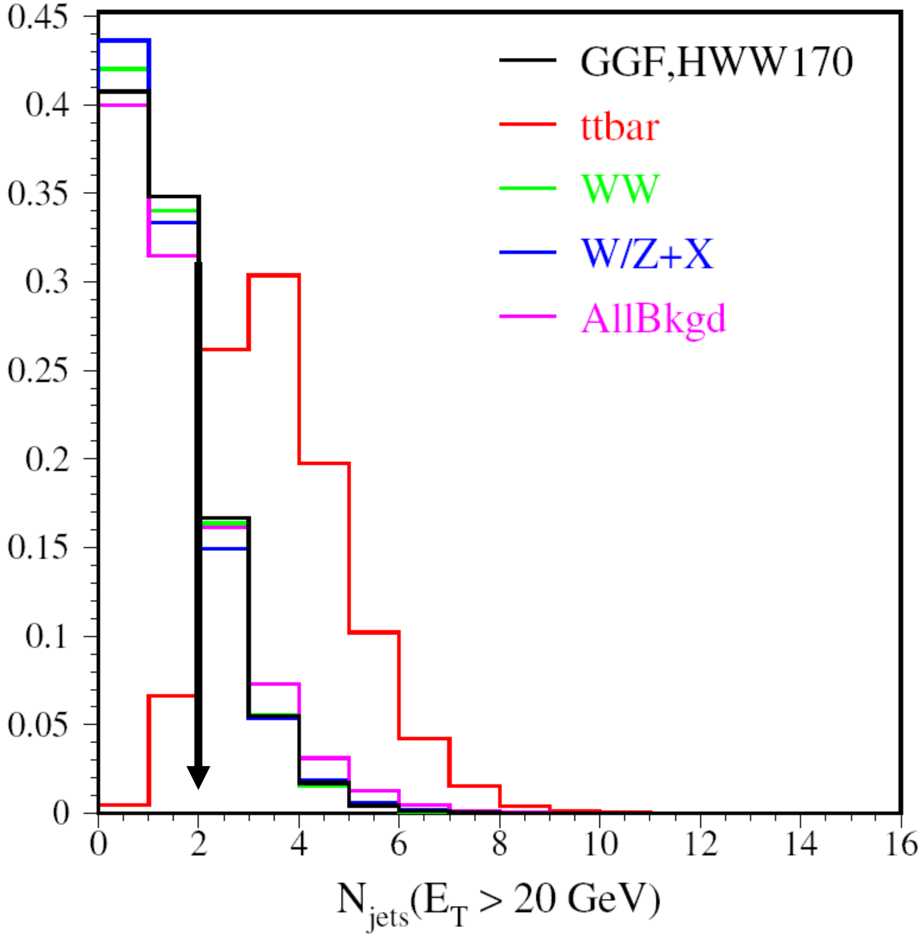
- Cut-based analysis
  - Optimize the straight cuts for better sensitivity
- Analysis based on Boosted Decision Trees (BDT)
- Consider two leptons with 0-jet and 1-jet events
- Results from cut-based and BDT analyses

Select H→WW→$l\nu l\nu$ with Straight Cuts

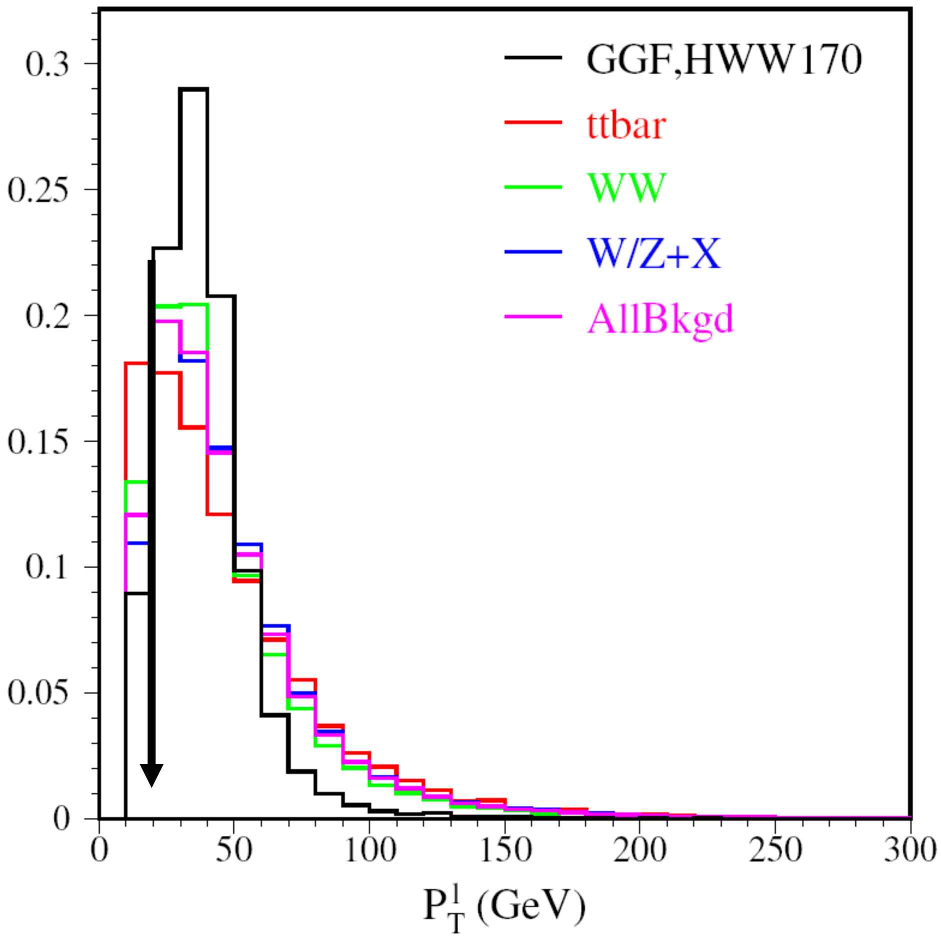
- Pt (l) > 20 GeV; Max (Pt(l1),Pt(l2)) > 25 GeV
- Lepton Isolation
  - In R=0.4 cone, ΣPt(μ) < 5 GeV
  - In R=0.4 cone, ΣPt(e) < 8 GeV
- MET > 50 GeV
- N_{jet} (Et>20 GeV) = 0 or 1
- $\Delta\phi$ (l1,l2) < 1.0
- 12 < M(l1,l2) < 50 GeV

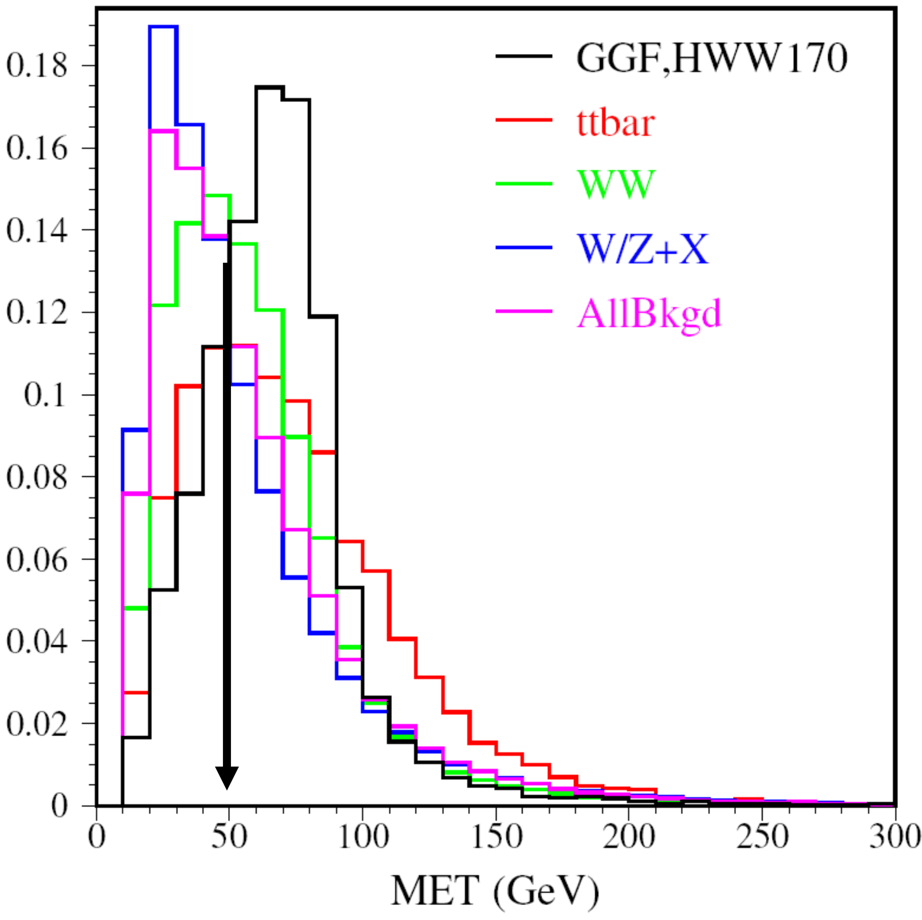
Some Variable Distributions After Pre-selection



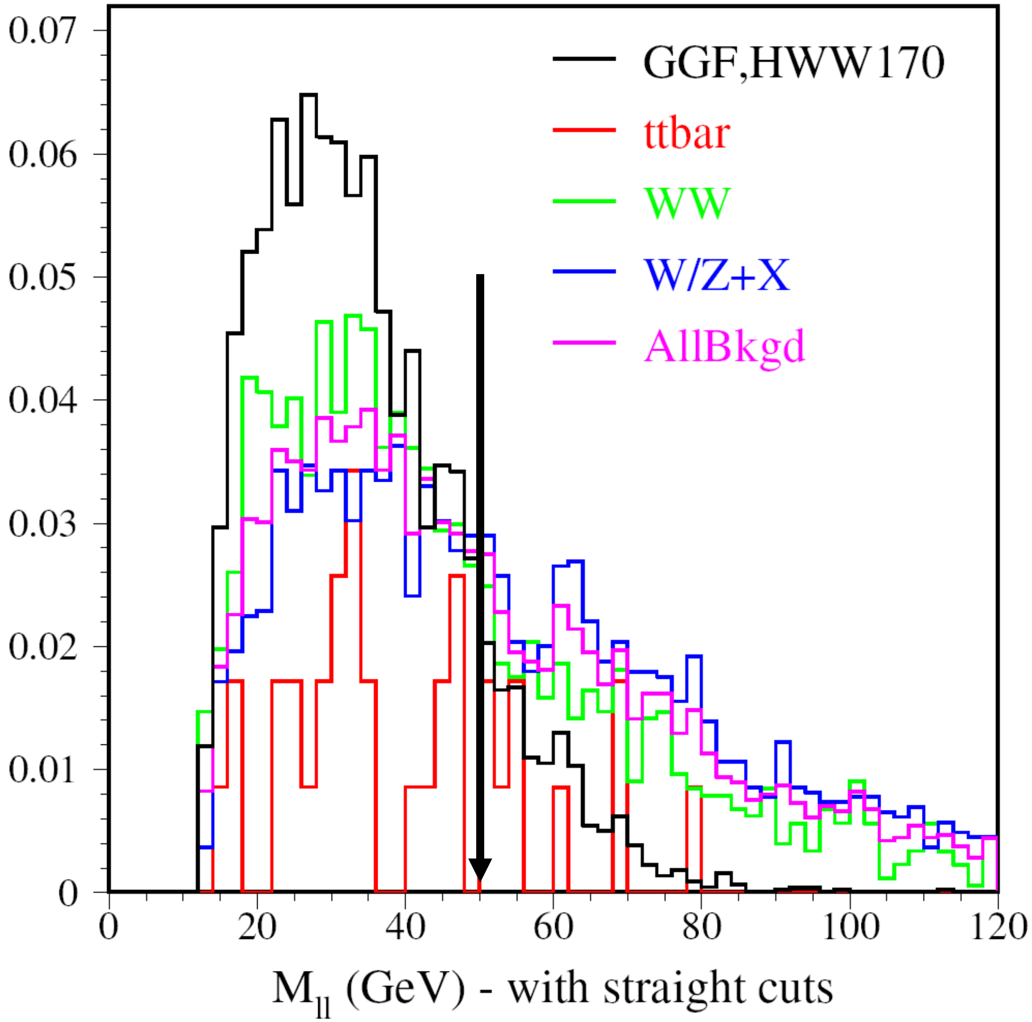


Some Variable Distributions After Pre-selection





Invariant Mass of two leptons (applied all cuts except M_{ll} cut)



Results from Cut-based Analysis (1/fb)

H→WW→lνlν Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	Bkgd
Cuts (eμ + 0 jet)	18.8	33.3	28.5	24.9	19.7	64.2
Cuts (eμ + 1 jet)	12.4	25.2	20.3	17.8	14.9	76.8
Cuts (eμ)	**31.2**	**58.5**	**48.8**	**42.7**	**34.6**	**141.0**
Cuts (ee + 0 jet)	6.3	11.3	9.9	8.1	6.8	80.6
Cuts (ee + 1 jet)	4.3	9.0	7.9	6.4	5.3	38.7
Cuts (ee)	**10.6**	**20.3**	**17.8**	**14.4**	**12.1**	**119.3**
Cuts (μμ + 0 jet)	10.1	18.5	15.7	13.3	10.3	33.3
Cuts (μμ + 1 jet)	7.0	13.3	11.2	10.4	8.7	58.4
Cuts (μμ)	**17.1**	**31.8**	**26.9**	**23.7**	**19.0**	**91.7**
Cuts (ee+μμ+eμ)	**58.9**	**110.6**	**93.5**	**80.8**	**65.7**	**352.0**

BDT Analysis

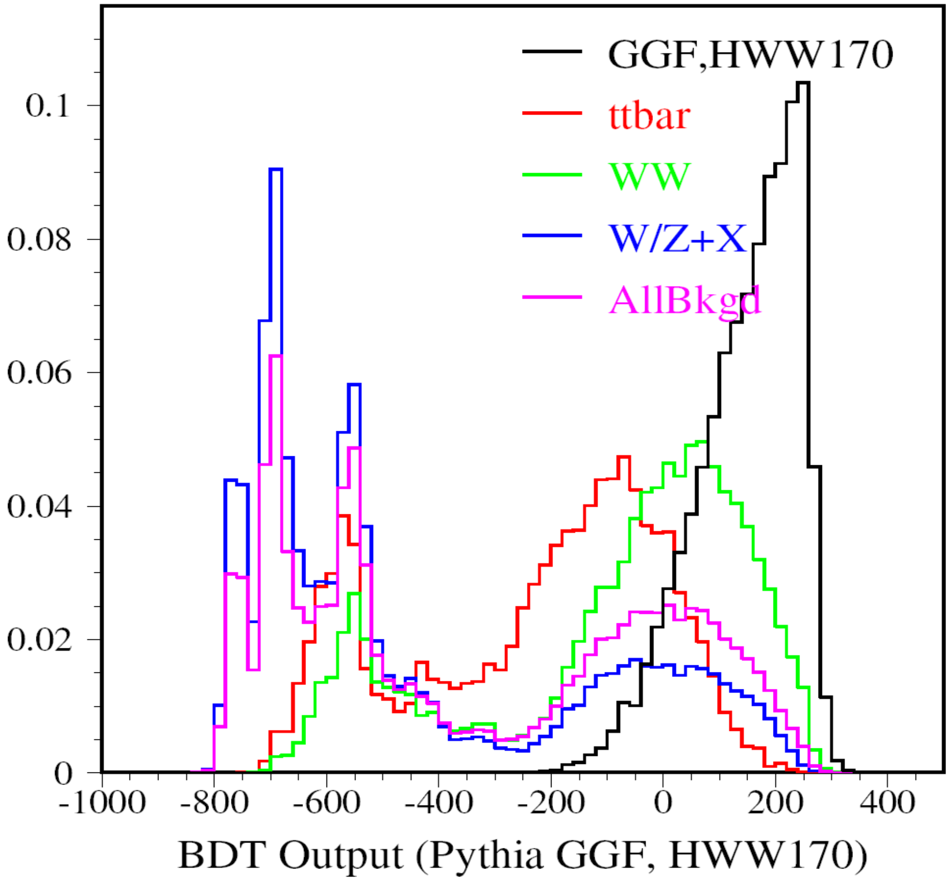
(H. Yang et.al., ATL-COM-PHYS-2008-023)

- **Signal for Training:** PYTHIA Gluon-Gluon fusion H → WW
- **Backgrounds for Training:** WW, ttbar, WZ, W+X and Z+X
- **Input variables for training:**

- Energy and Momentum
  - $p_T(\ell)$, $p_T(\ell,\ell)$
  - MET, total recoil E_T
  - scalar $\sum E_T(jet)$, vector $\sum E_T(\ell, MET)$
- Lepton Isolation
  - Number of tracks in $\Delta R < 0.4$ cone around ℓ
  - Sum of track p_T in $\Delta R < 0.4$ cone around ℓ
  - Sum of jet E_T in $\Delta R < 0.4$ cone around ℓ
- Event Topology
  - Number of Jets with $E_T > 20$ GeV
  - $E(\ell)/P(\ell)$
  - A0 (impact parameter) of ℓ, $\Delta A0(\ell,\ell)$, $\Delta Z(\ell,\ell)$
  - $\Delta R(\ell,\ell)$, $\Delta\phi(\ell,\ell)$, $\Delta\phi(\ell, MET)$
  - $\Delta\Omega(\ell,\ell)$ - opening angle of two leptons
- Mass Information
  - Invariant mass(ℓ,ℓ)
  - Transverse mass$(\ell\ell$,MET)
  - Transverse mass$(\ell$,MET)

BDT Ref: H. Yang et.al. NIM A555 (2005)370

BDT Discriminator



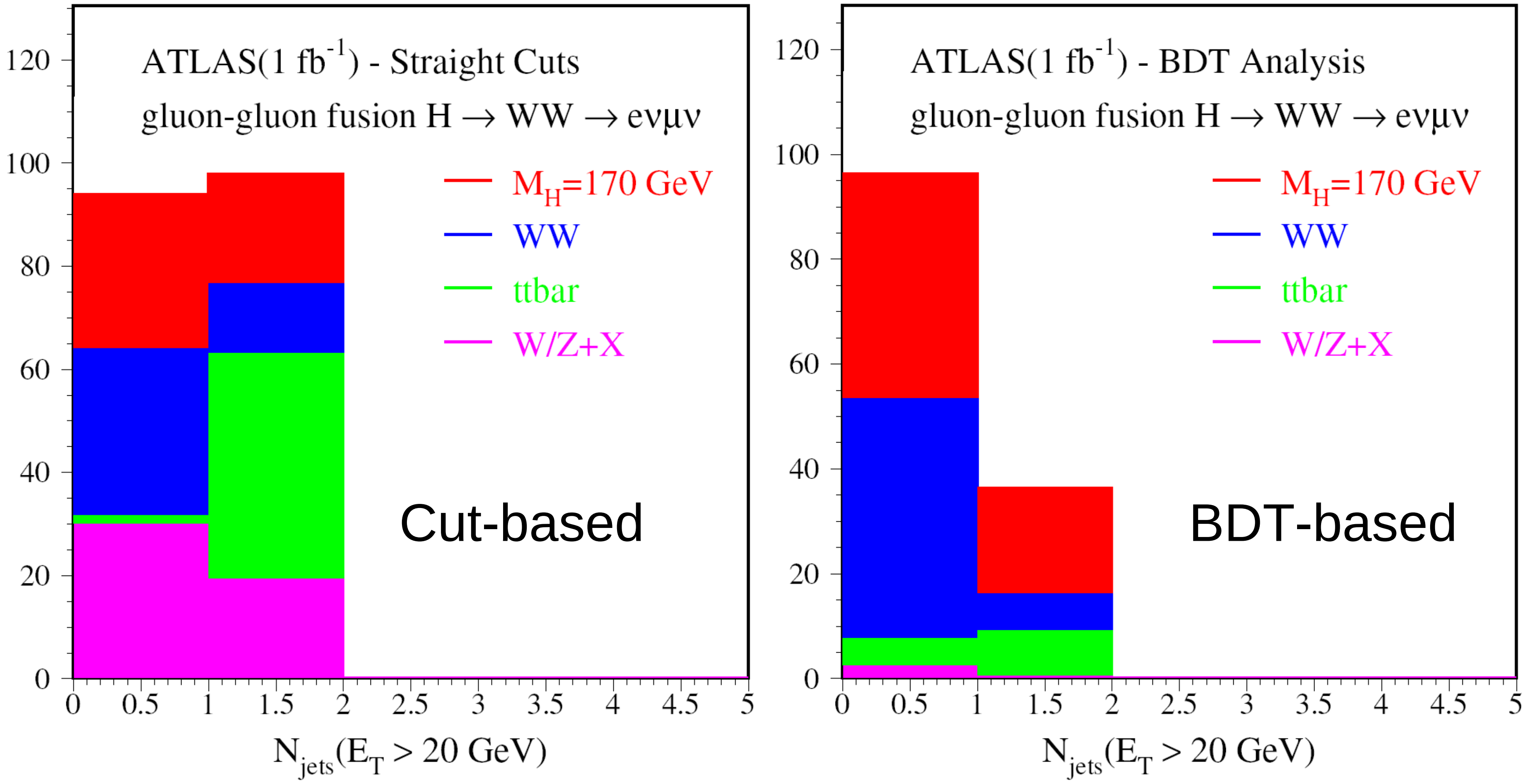
BDT discriminator is the total score of the BDT output as shown in left plot.

Event Selection:

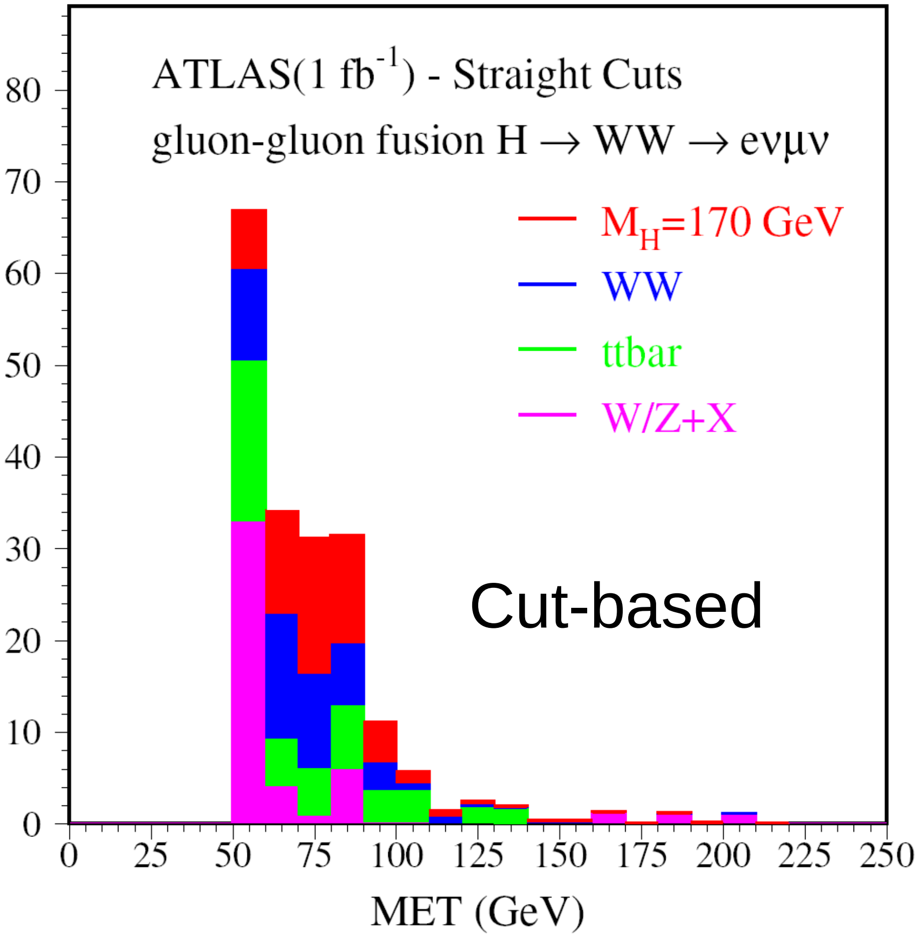
1) **For 0-jet events: BDT >=200**
2) **For 1-jet events: BDT >=220**

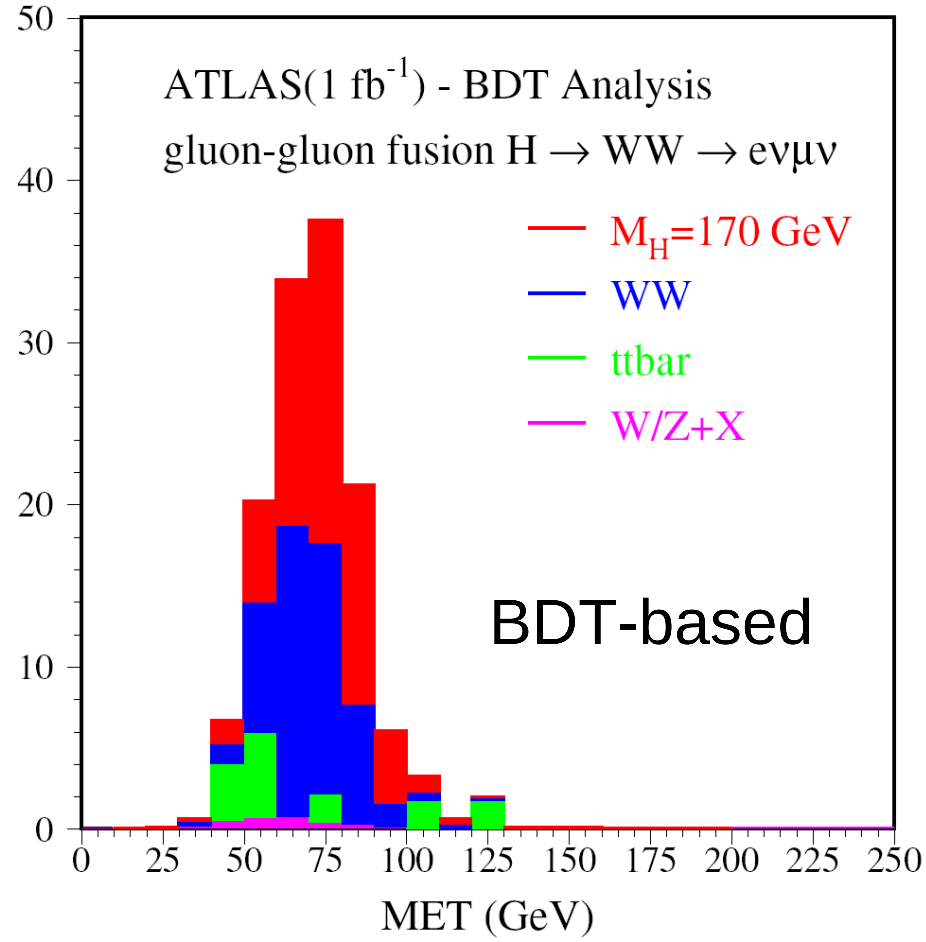
Detection sensitivity is defined as Significance = $N_S/\sqrt{N_B}$
(With or without systematic error)

Results (1/fb): Straight Cuts vs BDT

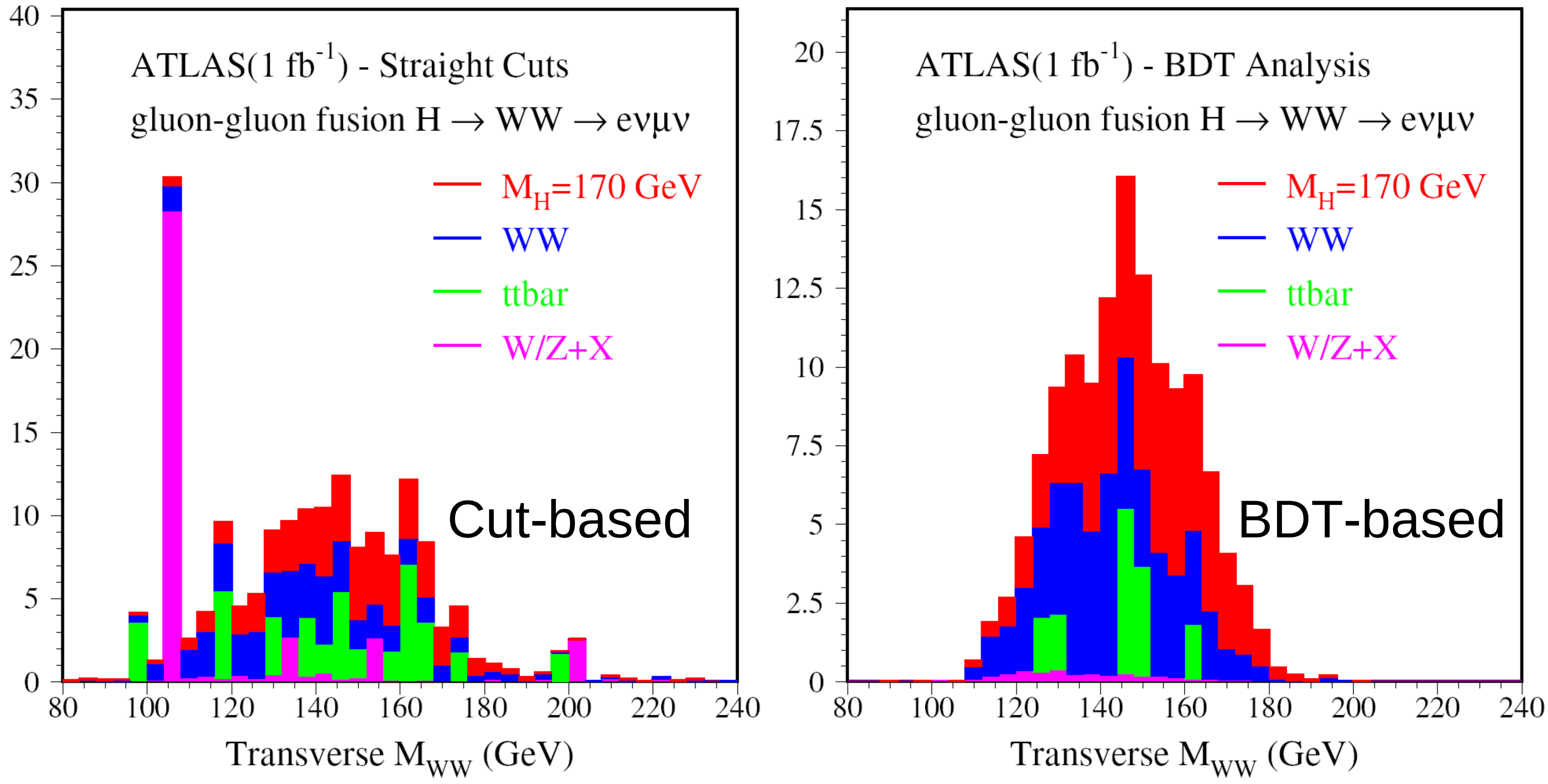


Results (1/fb): Straight Cuts vs BDT





Results (1/fb): Straight Cuts vs BDT



BDT Results: H → WW → eνμν (1/fb)

H→WW→eνμν Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	**Bkgd**
$\sigma_{pre-sel}$ (fb)	**169.6**	**210.1**	**196.4**	**194.0**	**180.0**	**38143**
BDT (0 jet)	22.5	45.1	41.0	36.6	29.4	53.6
BDT (1 jet)	9.3	21.8	19.2	16.4	13.3	16.3
BDT (0 jet+1 jet)	**31.8**	**67.0**	**60.2**	**53.0**	**42.7**	**69.8**

Cuts (0 jet)	18.8	33.3	28.5	24.9	19.7	64.2
Cuts (1 jet)	12.4	25.2	20.3	17.8	14.9	76.8
Cuts (0 jet+1 jet)	**31.2**	**58.5**	**48.8**	**42.7**	**34.6**	**141.0**

H → WW → μνμν (1/fb)

H→WW→μνμν Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	**Bkgd**
$\sigma_{pre-sel}$ **(fb)**	**94.6**	**117.0**	**103.4**	**96.4**	**86.8**	**44359**
BDT (0 jet)	13.2	25.3	22.8	20.6	17.1	39.1
BDT (1 jet)	7.9	16.3	13.1	11.4	8.4	19.3
BDT (0 jet+1 jet)	**21.1**	**41.6**	**35.9**	**32.0**	**25.5**	**58.4**
Cuts (0 jet)	10.1	18.5	15.7	13.3	10.3	33.3
Cuts (1 jet)	7.0	13.3	11.2	10.4	8.7	58.4
Cuts (0 jet+1 jet)	**17.1**	**31.8**	**26.9**	**23.7**	**19.0**	**91.7**

H → WW → eνeν (1/fb)

H→WW→eνeν Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	**Bkgd**
$\sigma_{pre\text{-}sel}$ (fb)	**58.1**	**71.0**	**84.4**	**64.4**	**62.4**	**150156**
BDT (0 jet)	11.2	17.8	16.7	15.1	14.2	56.8
BDT (1 jet)	6.3	12.8	11.0	9.2	7.8	33.2
BDT (0 jet+1 jet)	**17.5**	**30.6**	**27.7**	**24.3**	**22.0**	**90.0**

Cuts (0 jet)	6.3	11.3	9.9	8.1	6.8	80.6
Cuts (1 jet)	4.3	9.0	7.9	6.4	5.3	38.7
Cuts (0 jet+1 jet)	**10.6**	**20.3**	**17.8**	**14.4**	**12.1**	**119.3**

H → WW → $l\nu l\nu$ Selection
Statistical Sensitivity (1/fb)

GGF H→WW $N_s / \sqrt{N_b}$ (1/fb)	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV
Cuts (eμ)	**2.6**	**4.9**	**4.1**	**3.6**	**2.9**
Cuts ($\mu\mu$)	**1.8**	**3.3**	**2.8**	**2.5**	**2.0**
Cuts (ee)	**1.0**	**1.9**	**1.6**	**1.3**	**1.1**

BDT (eμ)	**3.8**	**8.0**	**7.2**	**6.3**	**5.1**
BDT ($\mu\mu$)	**2.8**	**5.4**	**4.7**	**4.2**	**3.3**
BDT (ee)	**1.8**	**3.2**	**2.9**	**2.6**	**2.3**

$H \rightarrow WW \rightarrow l\nu l\nu$ Selection Statistical Sensitivity (1/fb)

GGF H→WW Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	Bkgd
Cuts (ee+μμ+eμ) Efficiency	**58.9 7.7%**	**110.6 12.8%**	**93.5 11.3%**	**80.8 10.5%**	**65.7 9.2%**	**352.0**
$N_s / \sqrt{N_b}$ (no syst) **Cuts (ee+μμ+eμ)**	**3.1**	**5.9**	**5.0**	**4.3**	**3.5**	**N/A**
BDT (ee+μμ+eμ) Efficiency	**70.4 9.2%**	**139.2 16.1%**	**123.8 15.0%**	**109.3 14.2%**	**90.2 12.6%**	**218.2**
$N_s / \sqrt{N_b}$ (no syst) **BDT (ee+μμ+eμ)**	**4.8**	**9.4**	**8.4**	**7.4**	**6.1**	**N/A**

Systematic Uncertainties

- 6.5% Luminosity uncertainty (ref. Tevatron)
- 5% Parton Density Function uncertainty
- 3% Lepton identification acceptance uncertainty
- 5% Energy scale uncertainty (3% on lepton energy and 10% on hadronic energy)
- 6% BDT training uncertainty due to energy scale uncertainty and imperfect MC cross section estimation of major backgrounds)
- 15% background estimation uncertainty due to limited MC data sample statistics (W/Z+X)

➔ The total systematic uncertainty from above sources is 19%. We use conservative systematic error 20% for Higgs detection significance estimation.

Efficiency Change due to Uncertainties of Background Cross Sections

- To estimate systematic uncertainty caused by BDT training with imperfect MC background cross sections estimation, cross sections of main backgrounds (ww, tt) are changed by $\pm$20% for BDT training. The relative change of background with fixed signal efficiency are listed in the table.

Relative change of background	H→WW ($e\nu\mu\nu$)	H→WW ($\mu\nu\mu\nu$)	H→WW ($e\nu e\nu$)
σ_{WW} +20%	4.6%	2.0%	2.3%
σ_{WW} - 20%	6.8%	6.8%	8.4%
σ_{ttbar} +20%	2.4%	4.0%	3.1%
σ_{ttbar} - 20%	5.7%	1.1%	1.2%

Uncertainty from lepton and Jet Energy Scale and Resolution

- To estimate the systematic uncertainty, all energy-dependent variables in testing samples are modified by adding additional energy uncertainty, 3% for lepton and 10% for jets. The relative changes of signal and background efficiencies are calculated by using same BDT cut.

Relative change	H→WW (eνμν)	H→WW (μνμν)	H→WW (eνeν)
Signal (resolution)	<0.1%	0.1%	<0.1%
Signal (Scale)	1.1%	1.7%	2.6%
Background (resolution)	0.4%	0.9%	0.4%
Background (Scale)	3.1%	2.0%	5.6%

H → WW Detection Sensitivity (1/fb, with 20% systematic error)

GGF H→WW Events / fb	M_H=150 GeV	M_H=165 GeV	M_H=170 GeV	M_H=175 GeV	M_H=180 GeV	Bkgd
Cuts (ee+μμ+eμ)	**58.9**	**110.6**	**93.5**	**80.8**	**65.7**	**352.0**
$N_s / \sqrt{N_b+(0.2*N_b)^2}$ **Cuts (ee+μμ+eμ)**	**0.8**	**1.5**	**1.3**	**1.1**	**0.9**	**N/A**
$N_s / \sqrt{N_b+(0.2*N_b)^2}$ **Cuts (eμ)**	**1.0**	**1.9**	**1.6**	**1.4**	**1.1**	**N/A**

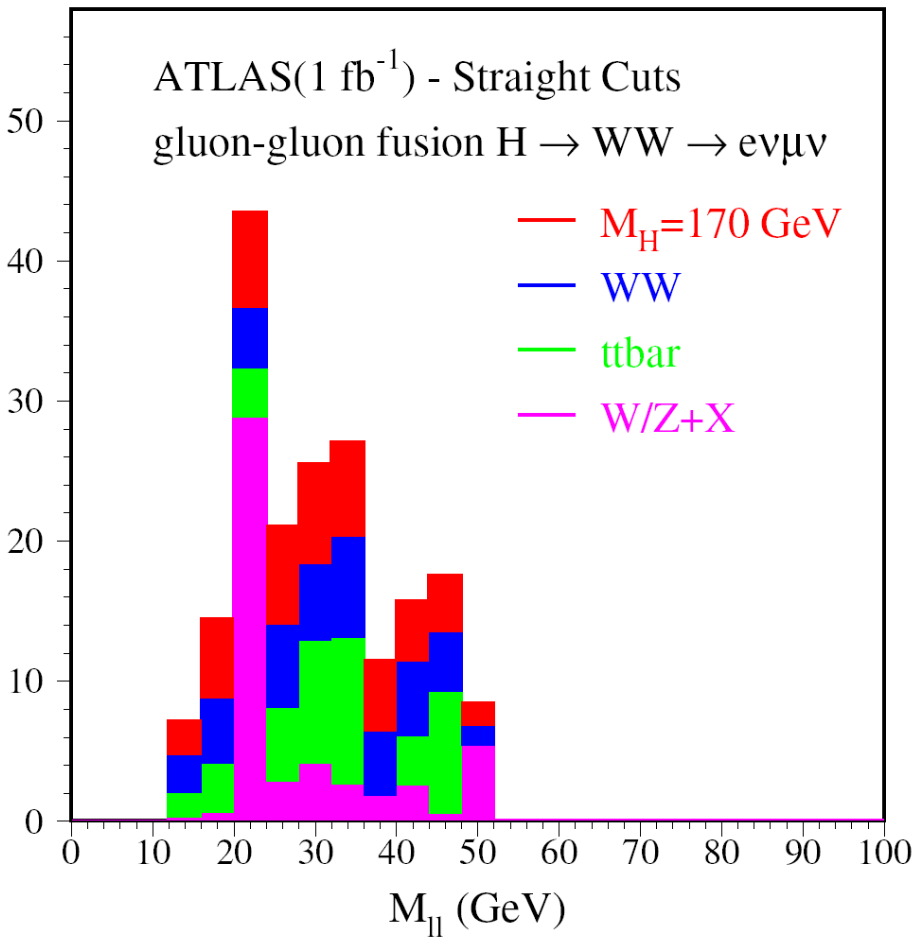
BDT (ee+μμ+eμ)	**70.4**	**139.2**	**123.8**	**109.3**	**90.2**	**218.2**
$N_s / \sqrt{N_b+(0.2*N_b)^2}$ **BDT (ee+μμ+eμ)**	**1.5**	**3.0**	**2.7**	**2.4**	**2.0**	**N/A**
$N_s / \sqrt{N_b+(0.2*N_b)^2}$ **BDT (eμ)**	**2.0**	**4.1**	**3.7**	**3.3**	**2.6**	**N/A**

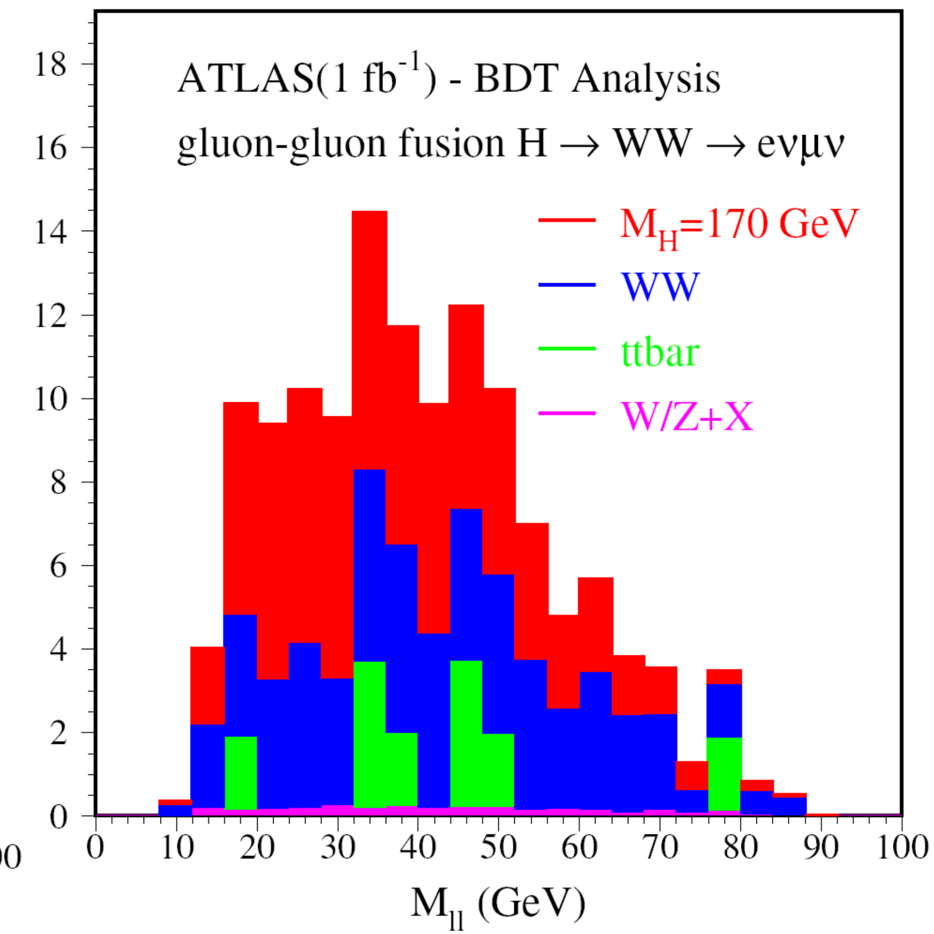
Summary

- Gluon-gluon fusion H→WW with three leptonic decay final states produced by Pythia MC generator are studied using large background samples.
- The BDT is a very useful analysis tool to improve the Higgs detection sensitivity.
- H→ WW channel could be a promising discovery channel in early LHC runs. It is crucial to control systematic uncertainties for a ‘counting’ experiment.
- Studies on VBF H→ WW analysis with 1 or 2 jets in events will be performed.

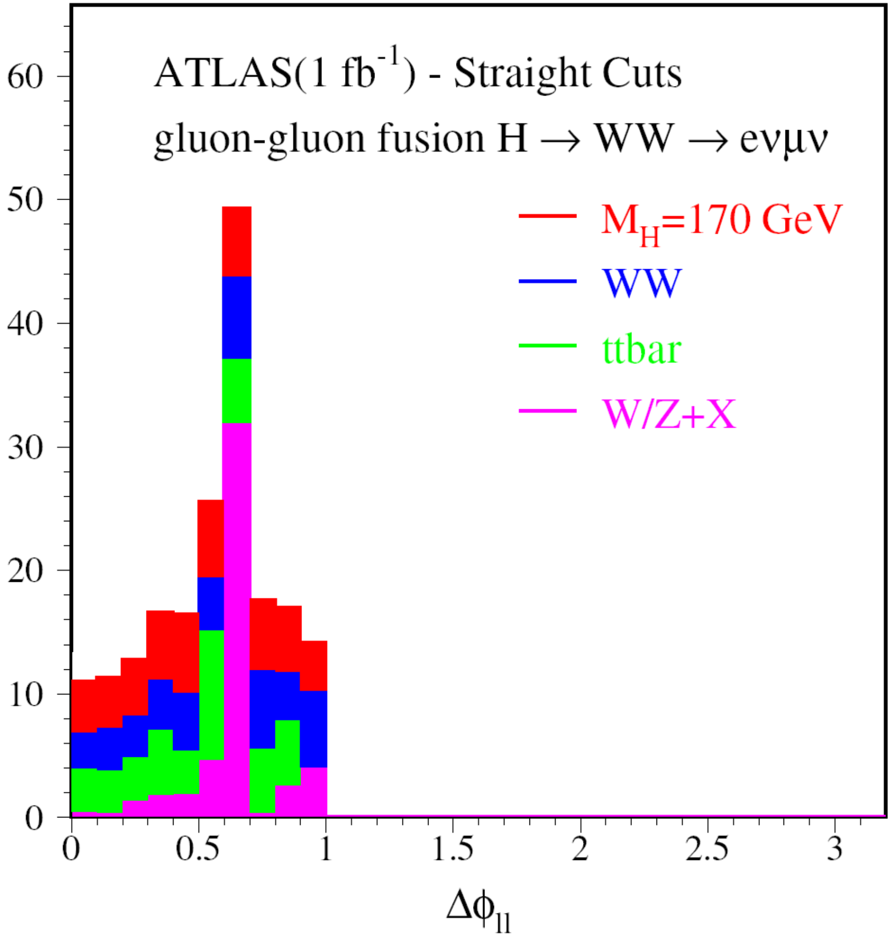
Backup slides

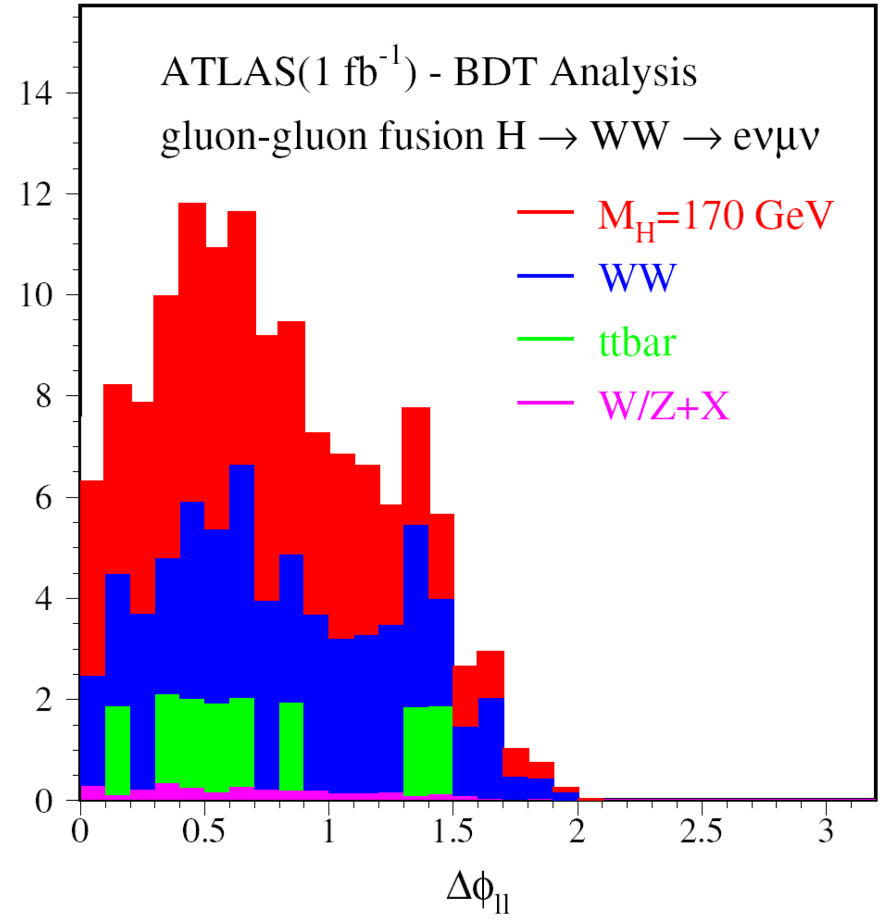
Results (1/fb): Straight Cuts vs BDT





Results (1/fb): Straight Cuts vs BDT





H → WW → eνeν

Gluon-Gluon fusion production of $H \to WW \to e\nu e\nu$								
Generator	Pythia			Backgrounds				
Events(fb^{-1})	N_s	N_{bg}	$S/\sqrt{B}$	N_{WW}	$N_{t\bar{t}}$	N_{WZ}	N_{WX}	N_{ZX}
$M_{Higgs} = 150$ GeV								
σ(fb)	200	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	58.1	150156	-	388	3930	75	3293	142253
Cuts(0 jet)	6.3	80.6	0.70	8.8	1.7	0.1	64.1	5.9
Cuts(1 jet)	4.3	38.7	0.69	5.0	14.0	0.3	0.0	19.5
Cuts(0jet+1jet)	10.6	119.3	0.97	13.8	15.7	0.4	64.1	25.4
$M_{Higgs} = 165$ GeV								
σ(fb)	226	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	71.0	150156	-	388	3930	75	3293	142253
Cuts(0 jet)	11.3	80.6	1.26	8.8	1.7	0.1	64.1	5.9
Cuts(1 jet)	9.0	38.7	1.45	5.0	14.0	0.3	0.0	19.5
Cuts(0jet+1jet)	20.3	119.3	1.86	13.8	15.7	0.4	64.1	25.4
$M_{Higgs} = 170$ GeV								
σ(fb)	206	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	84.4	150156	-	388	3930	75	3293	142253
Cuts(0 jet)	9.9	80.6	1.11	8.8	1.7	0.1	64.1	5.9
Cuts(1 jet)	7.9	38.7	1.27	5.0	14.0	0.3	0.0	19.5
Cuts(0jet+1jet)	17.8	119.3	1.63	13.8	15.7	0.4	64.1	25.4
$M_{Higgs} = 175$ GeV								
σ(fb)	201	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	64.4	150156	-	388	3930	75	3293	142253
Cuts(0 jet)	8.1	80.6	0.90	8.8	1.7	0.1	64.1	5.9
Cuts(1 jet)	6.4	38.7	1.03	5.0	14.0	0.3	0.0	19.5
Cuts(0jet+1jet)	14.4	119.3	1.32	13.8	15.7	0.4	64.1	25.4
$M_{Higgs} = 180$ GeV								
σ(fb)	186	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	62.4	150156	-	388	3930	75	3293	142253
Cuts(0 jet)	6.8	80.6	0.76	8.8	1.7	0.1	64.1	5.9
Cuts(1 jet)	5.3	38.7	0.84	5.0	14.0	0.3	0.0	19.5
Cuts(0jet+1jet)	12.1	119.3	1.11	13.8	15.7	0.4	64.1	25.4

Gluon-Gluon fusion production of $H \to WW \to e\nu e\nu$								
Generator	Pythia			Backgrounds				
Events(fb^{-1})	N_s	N_{bg}	$S/\sqrt{B}$	N_{WW}	$N_{t\bar{t}}$	N_{WZ}	N_{WX}	N_{ZX}
$M_{Higgs} = 150$ GeV								
σ(fb)	200	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	58.1	150156	-	388	3930	75	3293	142253
BDT(0 jet)	11.2	56.8	1.48	26.4	3.5	0.4	0.0	26.4
BDT(1 jet)	6.3	33.2	1.10	9.3	10.5	0.6	0.0	12.7
BDT(0jet+1jet)	17.5	90.0	1.84	35.7	14.0	1.0	0.0	39.1
$M_{Higgs} = 165$ GeV								
σ(fb)	226	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	71.0	150156	-	388	3930	75	3293	142253
BDT(0 jet)	17.8	56.8	2.36	26.4	3.5	0.4	0.0	26.4
BDT(1 jet)	12.8	33.2	2.23	9.3	10.5	0.6	0.0	12.7
BDT(0jet+1jet)	30.6	90.0	3.23	35.7	14.0	1.0	0.0	39.1
$M_{Higgs} = 170$ GeV								
σ(fb)	206	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	84.4	150156	-	388	3930	75	3293	142253
BDT(0 jet)	16.7	56.8	2.22	26.4	3.5	0.4	0.0	26.4
BDT(1 jet)	11.0	33.2	1.91	9.3	10.5	0.6	0.0	12.7
BDT(0jet+1jet)	27.7	90.0	2.92	35.7	14.0	1.0	0.0	39.1
$M_{Higgs} = 175$ GeV								
σ(fb)	201	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	64.4	150156	-	388	3930	75	3293	142253
BDT(0 jet)	15.1	56.8	2.01	26.4	3.5	0.4	0.0	26.4
BDT(1 jet)	9.2	33.2	1.59	9.3	10.5	0.6	0.0	12.7
BDT(0jet+1jet)	24.3	90.0	2.56	35.7	14.0	1.0	0.0	39.1
$M_{Higgs} = 180$ GeV								
σ(fb)	186	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	62.4	150156	-	388	3930	75	3293	142253
BDT(0 jet)	14.2	56.8	1.88	26.4	3.5	0.4	0.0	26.4
BDT(1 jet)	7.8	33.2	1.35	9.3	10.5	0.6	0.0	12.7
BDT(0jet+1jet)	22.0	90.0	2.32	35.7	14.0	1.0	0.0	39.1

H → WW → μνμν

Gluon-Gluon fusion production of $H \to WW \to \mu\nu\mu\nu$								
Generator	Pythia			Backgrounds				
Events(fb^{-1})	N_s	N_{bg}	$S/\sqrt{B}$	N_{WW}	$N_{t\bar{t}}$	N_{WZ}	N_{WX}	N_{ZX}
$M_{Higgs} = 150$ GeV								
σ(fb)	200	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	94.6	44359	-	571	6805	16.7	3784	33242
Cuts(0 jet)	10.1	33.3	1.76	18.1	0.0	0.4	0.0	14.9
Cuts(1 jet)	7.0	58.4	0.92	9.4	21.0	0.2	0.0	27.8
Cuts(0jet+1jet)	17.1	91.7	1.79	27.5	21.0	0.6	0.0	42.7
$M_{Higgs} = 165$ GeV								
σ(fb)	226	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	117.0	44359	-	571	6805	16.7	3784	33242
Cuts(0 jet)	18.5	33.3	3.21	18.1	0.0	0.4	0.0	14.9
Cuts(1 jet)	13.3	58.4	1.74	9.4	21.0	0.2	0.0	27.8
Cuts(0jet+1jet)	31.8	91.7	3.32	27.5	21.0	0.6	0.0	42.7
$M_{Higgs} = 170$ GeV								
σ(fb)	206	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	103.4	44359	-	571	6805	16.7	3784	33242
Cuts(0 jet)	15.7	33.3	2.71	18.1	0.0	0.4	0.0	14.9
Cuts(1 jet)	11.2	58.4	1.47	9.4	21.0	0.2	0.0	27.8
Cuts(0jet+1jet)	26.9	91.7	2.81	27.5	21.0	0.6	0.0	42.7
$M_{Higgs} = 175$ GeV								
σ(fb)	201	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	96.4	44359	-	571	6805	16.7	3784	33242
Cuts(0 jet)	13.3	33.3	2.31	18.1	0.0	0.4	0.0	14.9
Cuts(1 jet)	10.4	58.4	1.36	9.4	21.0	0.2	0.0	27.8
Cuts(0jet+1jet)	23.7	91.7	2.47	27.5	21.0	0.6	0.0	42.7
$M_{Higgs} = 180$ GeV								
σ(fb)	186	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	86.8	44359	-	571	6805	16.7	3784	33242
Cuts(0 jet)	10.3	33.3	1.79	18.1	0.0	0.4	0.0	14.9
Cuts(1 jet)	8.7	58.4	1.14	9.4	21.0	0.2	0.0	27.8
Cuts(0jet+1jet)	19.0	91.7	1.98	27.5	21.0	0.6	0.0	42.7

Gluon-Gluon fusion production of $H \to WW \to \mu\nu\mu\nu$								
Generator	Pythia			Backgrounds				
Events(fb^{-1})	N_s	N_{bg}	$S/\sqrt{B}$	N_{WW}	$N_{t\bar{t}}$	N_{WZ}	N_{WX}	N_{ZX}
$M_{Higgs} = 150$ GeV								
σ(fb)	200	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	94.6	44359	-	571	6805	16.7	3784	33242
BDT(0 jet)	13.2	39.1	2.11	28.9	0.0	0.8	0.0	9.4
BDT(1 jet)	7.9	19.3	1.79	6.8	5.2	0.2	0.0	7.1
BDT(0jet+1jet)	21.1	58.4	2.76	35.7	5.2	1.0	0.0	16.5
$M_{Higgs} = 165$ GeV								
σ(fb)	226	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	117.0	44359	-	571	6805	16.7	3784	33242
BDT(0 jet)	25.3	39.1	4.05	28.9	0.0	0.8	0.0	9.4
BDT(1 jet)	16.3	19.3	3.72	6.8	5.2	0.2	0.0	7.1
BDT(0jet+1jet)	41.6	58.4	5.44	35.7	5.2	1.0	0.0	16.5
$M_{Higgs} = 170$ GeV								
σ(fb)	206	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	103.4	44359	-	571	6805	16.7	3784	33242
BDT(0 jet)	22.8	39.1	3.65	28.9	0.0	0.8	0.0	9.4
BDT(1 jet)	13.1	19.3	2.99	6.8	5.2	0.2	0.0	7.1
BDT(0jet+1jet)	35.9	58.4	4.70	35.7	5.2	1.0	0.0	16.5
$M_{Higgs} = 175$ GeV								
σ(fb)	201	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	96.4	44359	-	571	6805	16.7	3784	33242
BDT(0 jet)	20.6	39.1	3.30	28.9	0.0	0.8	0.0	9.4
BDT(1 jet)	11.4	19.3	2.60	6.8	5.2	0.2	0.0	7.1
BDT(0jet+1jet)	32.0	58.4	4.19	35.7	5.2	1.0	0.0	16.5
$M_{Higgs} = 180$ GeV								
σ(fb)	186	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	86.8	44359	-	571	6805	16.7	3784	33242
BDT(0 jet)	17.1	39.1	2.74	28.9	0.0	0.8	0.0	9.4
BDT(1 jet)	8.4	19.3	1.91	6.8	5.2	0.2	0.0	7.1
BDT(0jet+1jet)	25.5	58.4	3.34	35.7	5.2	1.0	0.0	16.5

H → WW → eνμν

Gluon-Gluon fusion production of $H \to WW \to e\nu\mu\nu$								
Generator	Pythia			Backgrounds				
Events(fb^{-1})	N_s	N_{bg}	$S/\sqrt{B}$	N_{WW}	$N_{t\bar{t}}$	N_{WZ}	N_{WX}	N_{ZX}
$M_{Higgs} = 150$ GeV								
σ(fb)	400	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	169.6	38143	-	1204	14098	126	11702	11029
Cuts(0 jet)	18.8	64.2	2.35	32.4	1.7	1.5	28.0	0.5
Cuts(1 jet)	12.4	76.8	1.41	13.6	43.7	1.2	0.0	18.3
Cuts(0jet+1jet)	31.2	141.0	2.63	46.0	45.5	2.7	28.0	18.8
$M_{Higgs} = 165$ GeV								
σ(fb)	452	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	210.1	38143	-	1204	14098	126	11702	11029
Cuts(0 jet)	33.3	64.2	4.16	32.4	1.7	1.5	28.0	0.5
Cuts(1 jet)	25.2	76.8	2.87	13.6	43.7	1.2	0.0	18.3
Cuts(0jet+1jet)	58.5	141.0	4.93	46.0	45.5	2.7	28.0	18.8
$M_{Higgs} = 170$ GeV								
σ(fb)	412	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	196.4	38143	-	1204	14098	126	11702	11029
Cuts(0 jet)	28.5	64.2	3.56	32.4	1.7	1.5	28.0	0.5
Cuts(1 jet)	20.3	76.8	2.31	13.6	43.7	1.2	0.0	18.3
Cuts(0jet+1jet)	48.8	141.0	4.11	46.0	45.5	2.7	28.0	18.8
$M_{Higgs} = 175$ GeV								
σ(fb)	402	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	194.0	38143	-	1204	14098	126	11702	11029
Cuts(0 jet)	24.9	64.2	3.11	32.4	1.7	1.5	28.0	0.5
Cuts(1 jet)	17.8	76.8	2.03	13.6	43.7	1.2	0.0	18.3
Cuts(0jet+1jet)	42.7	141.0	3.59	46.0	45.5	2.7	28.0	18.8
$M_{Higgs} = 180$ GeV								
σ(fb)	372	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	180.0	38143	-	1204	14098	126	11702	11029
Cuts(0 jet)	19.7	64.2	2.46	32.4	1.7	1.5	28.0	0.5
Cuts(1 jet)	14.9	76.8	1.70	13.6	43.7	1.2	0.0	18.3
Cuts(0jet+1jet)	34.6	141.0	2.92	46.0	45.5	2.7	28.0	18.8

Gluon-Gluon fusion production of $H \to WW \to e\nu\mu\nu$								
Generator	Pythia			Backgrounds				
Events(fb^{-1})	N_s	N_{bg}	$S/\sqrt{B}$	N_{WW}	$N_{t\bar{t}}$	N_{WZ}	N_{WX}	N_{ZX}
$M_{Higgs} = 150$ GeV								
σ(fb)	400	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	169.6	38143	-	1204	14098	126	11702	11029
BDT(0 jet)	22.5	53.6	3.08	45.8	5.2	2.4	0.0	0.1
BDT(1 jet)	9.3	16.3	2.30	7.0	8.7	0.6	0.0	0.0
BDT(0jet+1jet)	31.8	69.8	3.80	52.8	13.9	3.0	0.0	0.1
$M_{Higgs} = 165$ GeV								
σ(fb)	452	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	210.1	38143	-	1204	14098	126	11702	11029
BDT(0 jet)	45.1	53.6	6.16	45.8	5.2	2.4	0.0	0.1
BDT(1 jet)	21.8	16.3	5.41	7.0	8.7	0.6	0.0	0.0
BDT(0jet+1jet)	67.0	69.8	8.01	52.8	13.9	3.0	0.0	0.1
$M_{Higgs} = 170$ GeV								
σ(fb)	412	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	196.4	38143	-	1204	14098	126	11702	11029
BDT(0 jet)	41.0	53.6	5.61	45.8	5.2	2.4	0.0	0.1
BDT(1 jet)	19.2	16.3	4.77	7.0	8.7	0.6	0.0	0.0
BDT(0jet+1jet)	60.2	69.8	7.21	52.8	13.9	3.0	0.0	0.1
$M_{Higgs} = 175$ GeV								
σ(fb)	402	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	194.0	38143	-	1204	14098	126	11702	11029
BDT(0 jet)	36.6	53.6	5.00	45.8	5.2	2.4	0.0	0.1
BDT(1 jet)	16.4	16.3	4.06	7.0	8.7	0.6	0.0	0.0
BDT(0jet+1jet)	53.0	69.8	6.34	52.8	13.9	3.0	0.0	0.1
$M_{Higgs} = 180$ GeV								
σ(fb)	372	-	-	12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	180.0	38143	-	1204	14098	126	11702	11029
BDT(0 jet)	29.4	53.6	4.01	45.8	5.2	2.4	0.0	0.1
BDT(1 jet)	13.3	16.3	3.29	7.0	8.7	0.6	0.0	0.0
BDT(0jet+1jet)	42.7	69.8	5.10	52.8	13.9	3.0	0.0	0.1

Detection Sensitivity Comparison using PYTHIA and MC@NLO

Gluon-Gluon fusion production of $H \to WW \to e\nu\mu\nu$, $M_{Higgs} = 170$ GeV											
Generator	Pythia			MCatNLO			Backgrounds				
Events/fb	N_s	N_{bg}	$S/\sqrt{B}$	N_s	N_{bg}	$S/\sqrt{B}$	N_{WW}	$N_{t\bar{t}}$	N_{WZ}	N_{WX}	N_{ZX}
σ(fb)	412			412			12701	462315	688	5.8E7	5.4E7
$\sigma_{pre-sel}$(fb)	196	39803	0.98	161	39803	0.81	1204	14098	126	11702	12697
Cuts(0 jet)	28.5	64	3.56	12.6	64	1.57	32.4	1.7	1.5	28.0	0.5
Cuts(1 jet)	20.3	77	2.31	9.5	77	1.08	13.6	43.7	1.2	0.0	18.3
Cuts(0jet+1jet)	48.8	141	4.11	22.0	141	1.86	46.0	45.5	2.8	28.0	18.8
BDT(0 jet)	41.0	54	5.61	18.0	54	2.45	45.8	5.2	2.4	0.0	0.1
BDT(1 jet)	19.2	16	4.77	7.3	16	1.82	7.0	8.7	0.6	0.0	0.0
BDT(0jet+1jet)	60.2	70	7.21	25.3	70	3.03	52.8	13.9	3.0	0.0	0.1

Table 2: Comparison of Higgs detection sensitivity through the process $H \to WW \to e\nu\mu\nu$ using PYTHIA and MCatNLO MC generators. The $H \to WW$ spin-spin correlations have been taken into account in PYTHIA, but not in MCatNLO. The cross-sections listed in the table are all normalized to NLO calculations. The W decay to electron or muon branching ratio of 0.108 has been used, also MC Higgs event generation filter efficiency of 0.96 has been applied.

Signal efficiencies with PYTHIA are higher than that with MC@NLO by more than a factor of 2 in both straight-cut and BDT analysis!

More Comparisons

Using Similar HG4 CSC note cuts:

- Pt (l) > 15 GeV, $|\eta_l| < 2.5$
- 12 < M(l1,l2) < 300 GeV
- $\Delta\phi$ (l1,l2) < 1.575
- MET > 30 GeV
- N_{jet} (Et>20 GeV) = 0
- In R=0.4 cone, ΣPt(μ) < 5 GeV
- In R=0.4 cone, ΣPt(e) < 8 GeV

Using HG4 Cuts, Normalize to 1/fb integrated luminosity

M_{Higgs} (GeV)	Pythia N_{precut}	Pythia N_s	Pythia Eff_s	Pythia N_s/N_{bg}	Pythia $N_s/\sqrt{N_{bg}}$
150	169.6	42.1	24.8%	0.07	1.73
165	210.1	61.6	29.3%	0.11	2.54
170	196.4	54.9	27.9%	0.09	2.26
175	194.0	50.8	26.2%	0.09	2.10
180	180.0	43.9	24.4%	0.08	1.81

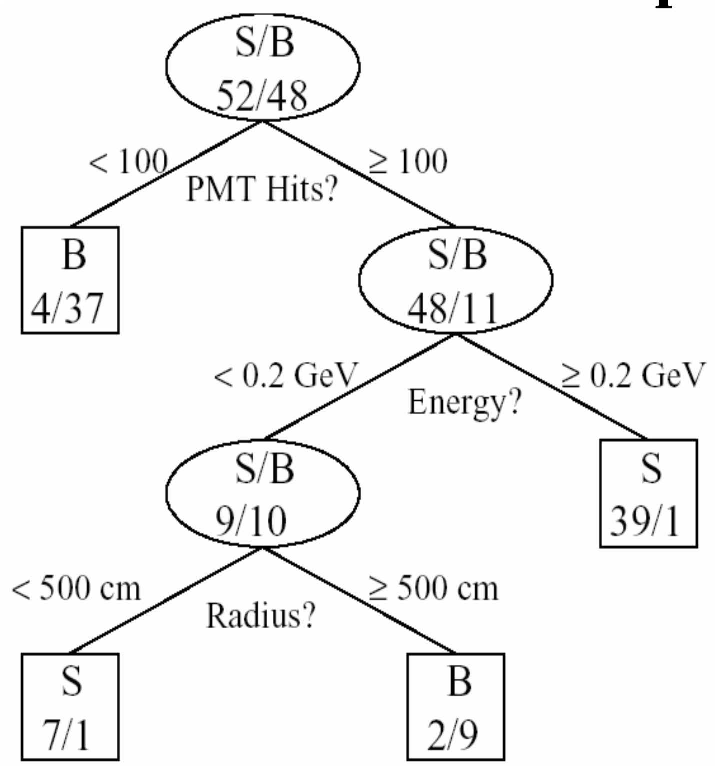
M_{Higgs} (GeV)	MC@NLO N_{precut}	MC@NLO N_s	MC@NLO Eff_s	MC@NLO N_s/N_{bg}	MC@NLO $N_s/\sqrt{N_{bg}}$
150	168.2	32.7	19.5%	0.06	1.35
165	210.3	47.6	22.6%	0.08	1.96
170	160.9	30.4	18.9%	0.05	1.26
175	190.0	38.3	20.1%	0.07	1.58
180	178.3	34.3	19.3%	0.06	1.42

BG_{total}	WW	Ttbar	WZ	W+X	Z+X
39802.5	1203.6	14097.7	126.3	11702.4	12696.8
588.5	142.0	10.5	13.5	401.1	21.4

Boosted Decision Trees

➔Relatively new in HEP – MiniBooNE, BaBar, D0(single top discovery), ATLAS
➔Advantages: robust, understand 'powerful' variables, relatively transparent, …

"A procedure that combines many weak classifiers to form a powerful committee"



BDT Training Process

- Split data recursively based on input variables until a stopping criterion is reached (e.g. purity, too few events)
- Every event ends up in a "signal" or a "background" leaf
- Misclassified events will be given larger weight in the next decision tree (boosting)

H. Yang et.al. NIM A555 (2005)370, NIM A543 (2005)577, NIM A574(2007) 342

A set of decision trees can be developed,

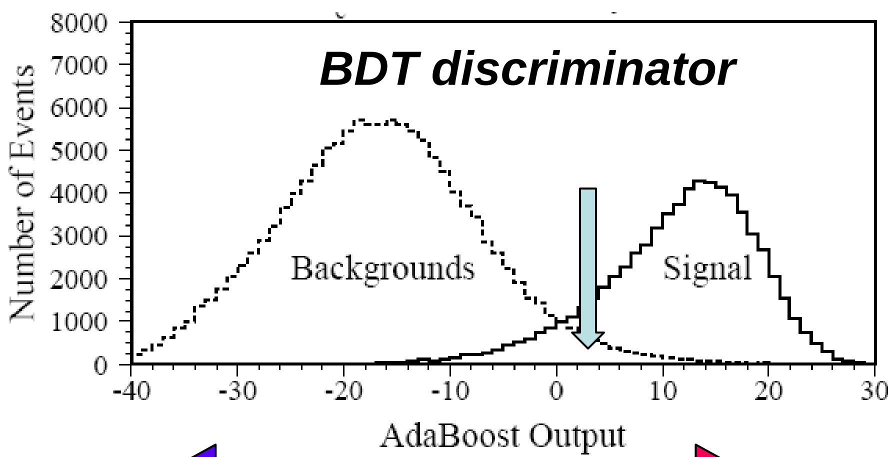
each re-weighting the events to enhance identification of backgrounds misidentified by earlier trees (“boosting”)

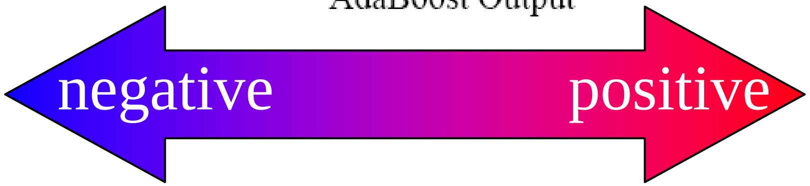
For each tree, the data event is assigned

+1 if it is identified as signal,

- 1 if it is identified as background.

The total for all trees is combined into a “**score**”



Background-like 

signal-like