Analysis of H → WW → lνlν Based on Boosted Decision Trees

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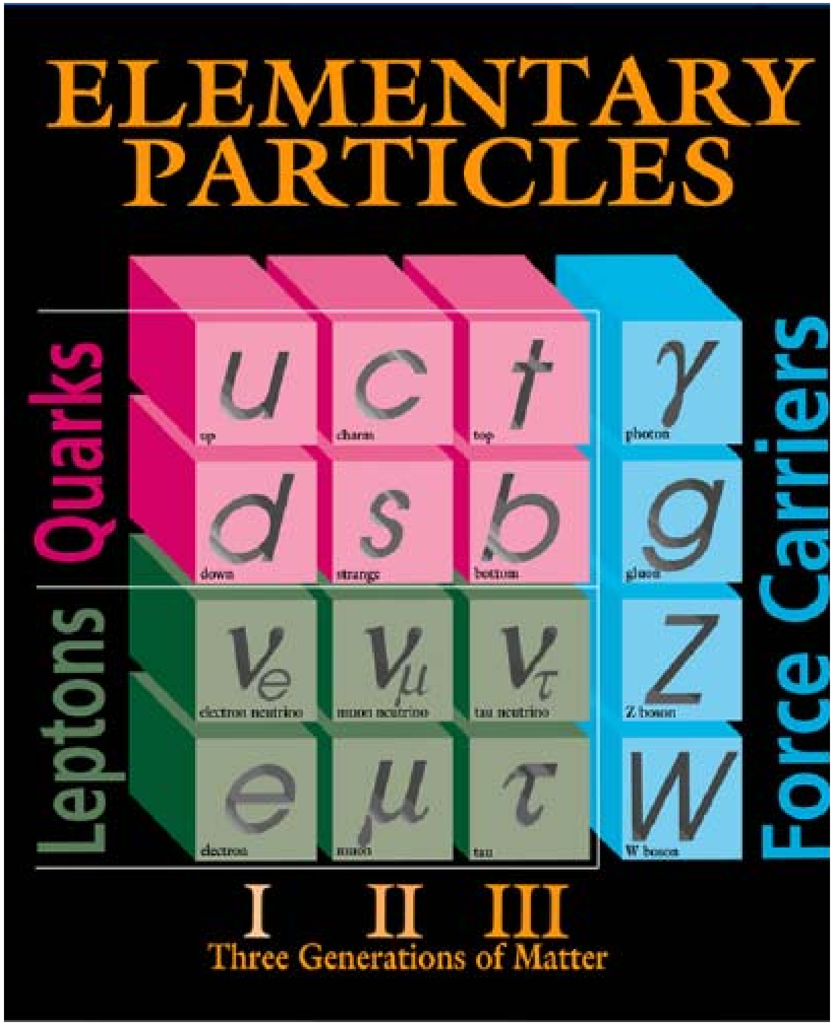
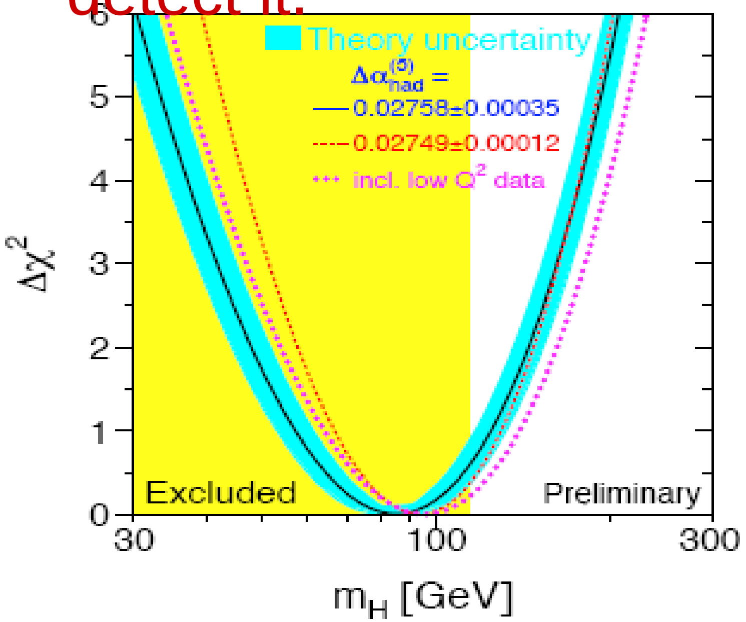
Outline

- Physics Motivation
- MC samples for H $\rightarrow$ WW analysis
- Introduction of Boosted Decision Trees (BDT)
- H $\rightarrow$ WW analysis based on BDT
- Sensitivity of H $\rightarrow$ WW $\rightarrow$ $l\nu l\nu$
- Summary

The Standard Model

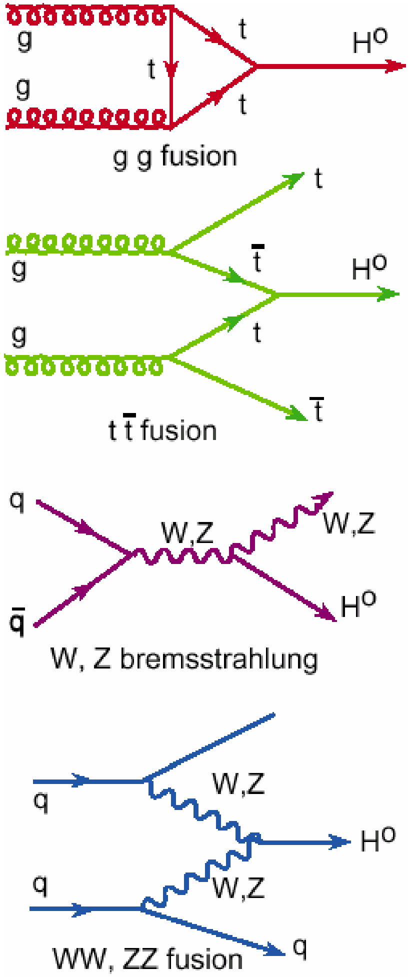


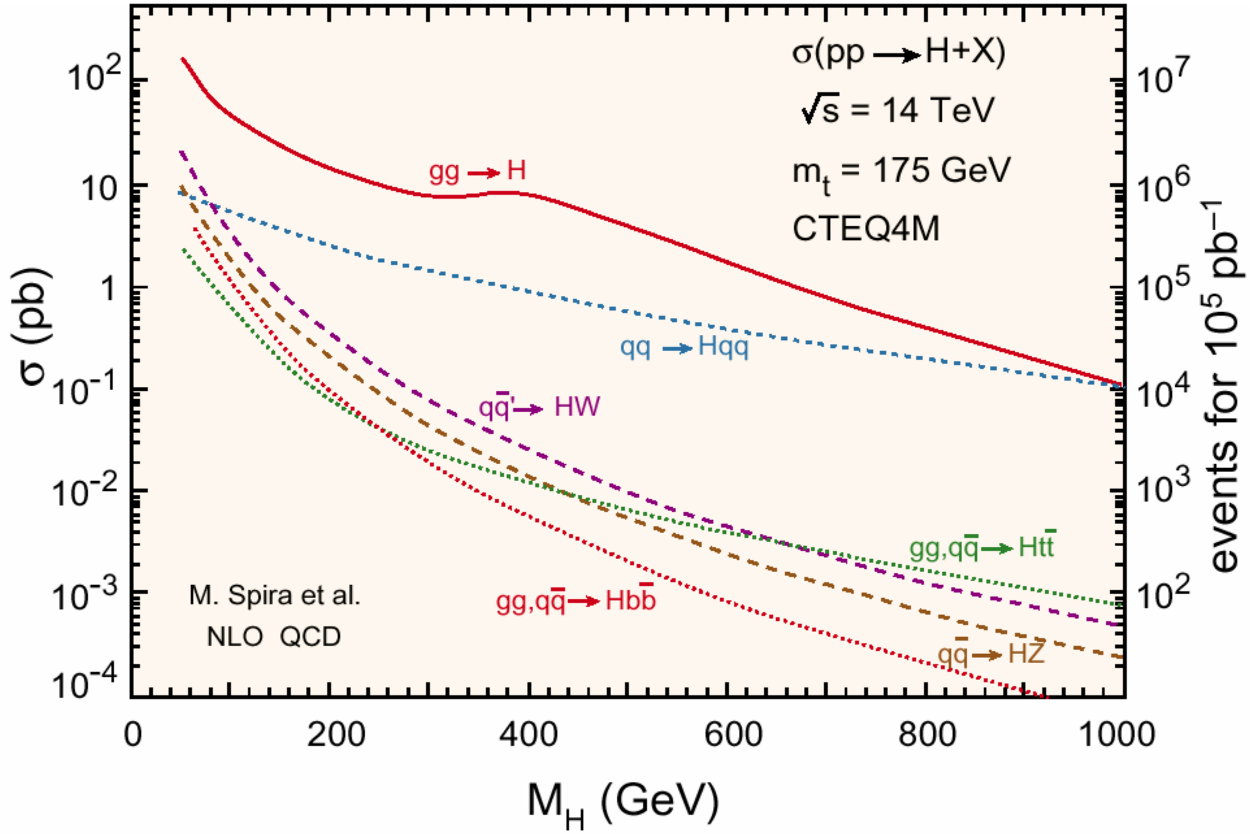
➔ Why particles have mass?
Higgs mechanism ?
If SM Higgs boson exists, the LHC will be able to detect it.



Standard-Model $M_H \lesssim 200$ GeV at 95% CL

Higgs Production at LHC





Having available four production mechanisms is a key for measurements of Higgs parameters

BR and Discovery Channels

Low mass region: m(H) < 2 m_Z

$H \to \gamma\gamma$

$H \to bb$

$H \to \tau\tau$

$H \to ZZ^* \to 4\ell$

$H \to WW^* \to \ell\nu\ell\nu$ or $\ell\nu jj$

m(H) > 2 m_Z

$H \to ZZ \to 4\ell$

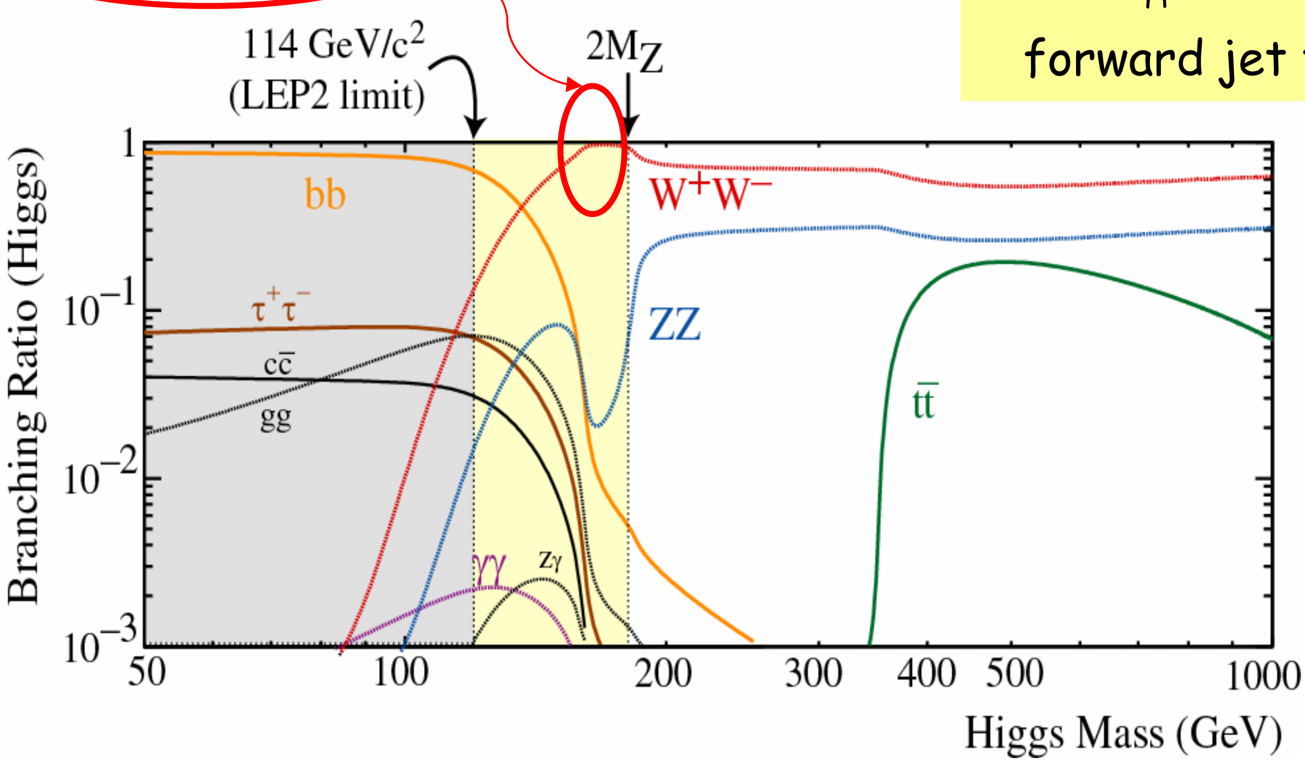
$qqH \to ZZ \to \ell\ell\ \nu\nu$ *

$qqH \to ZZ \to \ell\ell\ jj$ *

$qqH \to WW \to \ell\nu jj$ *

* for m_H > 300 GeV

forward jet tag



$H \rightarrow WW \rightarrow l\nu l\nu$

- Signal $H \rightarrow WW$ using CSC V12
- All background MC using CSC V11
- $gg \rightarrow WW$ MC are not available for this study
- Full ATLAS detector simulation

- $H \rightarrow WW \rightarrow e\nu e\nu$, $\mu\nu\mu\nu$, $e\nu\mu\nu$
- Higgs production based on gg fusion & VBF
- Higgs masses:
  - 140, 150, 160, 165, 170, 180 GeV

Pre-selection Efficiency

- At least one lepton pair (ee, μμ, eμ) with Pt>10 GeV
- Missing Et > 15 GeV
- $|M_{ee} - M_z| > 10$ GeV, $|M_{\mu\mu} - M_z| > 15$ GeV to suppress background from Z → ee, μμ

Higgs Mass (GeV)	Eff(eeX)	Eff($\mu\mu X$)	Eff($e\mu X$)
140	27.0%	53.9%	39.0%
150	29.2%	54.6%	41.1%
160	30.4%	56.3%	43.2%
165	31.0%	56.8%	43.8%
170	31.1%	55.4%	45.0%
180	29.7%	52.4%	45.8%
WW	28.0%	42.8%	39.0%

MC for $H \rightarrow WW \rightarrow e\nu e\nu$ Analysis

	MC Process	ID	σ_{mc}(fb)	K	Br	N_{mc}	N_{precut}	N_{test}	Weight
Higgs Signal	ww_ee_higgs140	0	0.4132E+03	2.027	0.2500	117800	7943	14.1	0.00178
	ww_ee_higgs150	0	0.5122E+03	1.986	0.2500	118400	8629	18.5	0.00215
	ww_ee_higgs160	0	0.6003E+03	1.941	0.2500	167600	12755	22.2	0.00174
	ww_ee_higgs165	0	0.6056E+03	1.923	0.2500	217100	16827	22.6	0.00134
	ww_ee_higgs170	0	0.5804E+03	1.917	0.2500	167200	12995	21.6	0.00166
	ww_ee_higgs180	0	0.5107E+03	1.910	0.2500	118700	8810	18.1	0.00205
SM Background	ww_ee	1	0.1133E+06	1.0	0.0120	43100	12071	380.8	0.0315
	wpz_lnull	2	0.3673E+05	1.0	0.0144	27000	783	15.3	0.0196
	wmz_lnull	3	0.2099E+05	1.0	0.0144	17700	536	9.2	0.0171
	z_2mu	4	0.4610E+08	1.3	0.0336	1153109	0	0.0	1.7463
	zgamma_ll	5	0.8910E+06	1.5	0.0672	999742	4799	431.1	0.0898
	zjet010_mumu	6	0.1360E+08	1.3	0.0336	2996413	1	0.2	0.1983
	zjet020_mumu	7	0.8670E+07	1.3	0.0336	1995792	1	0.2	0.1898
	zjet040_mumu	8	0.4120E+07	1.3	0.0336	1189793	0	0.0	0.1513
	zjet080_mumu	9	0.8270E+06	1.3	0.0336	397856	0	0.0	0.0908
	zjet120_mumu	10	0.3830E+06	1.3	0.0336	199832	0	0.0	0.0837
	ttbar	11	0.7590E+06	1.0	0.5550	622000	6030	4083.8	0.6772
	ww_emu	12	0.1133E+06	1.0	0.0120	47050	8	0.2	0.0289
	ww_etau	13	0.1133E+06	1.0	0.0120	73850	2199	40.5	0.0184
	ww_mue	14	0.1133E+06	1.0	0.0120	48050	9	0.3	0.0283
	ww_mumu	15	0.1133E+06	1.0	0.0120	49000	0	0.0	0.0277
	ww_mutau	16	0.1133E+06	1.0	0.0120	45050	0	0.0	0.0302
	ww_taue	17	0.1133E+06	1.0	0.0120	48400	1472	41.3	0.0281
	ww_taumu	18	0.1133E+06	1.0	0.0120	47350	0	0.0	0.0287
	ww_tautau	19	0.1133E+06	1.0	0.0120	36150	111	4.2	0.0376
	zz_llll	20	0.1886E+05	1.0	0.0045	36400	216	0.5	0.0023
	w_e	21	0.1580E+09	1.3	0.1072	2493962	289	2551.5	8.8289
	w_mu	22	0.1580E+09	1.3	0.1072	1997396	2	22.0	11.0238
	w_tau	23	0.1580E+09	1.3	0.1072	2494806	22	194.2	8.8259
	wgamma_l	24	0.1420E+07	1.0	0.2144	1996438	265	40.4	0.1525
	wgamma_tau	25	0.1420E+07	1.0	0.1072	999999	22	3.3	0.1522
	dy010_2lep	26	0.3390E+08	1.3	0.1010	2401998	375	694.9	1.8531
	dy020_2lep	27	0.5090E+07	1.3	0.1010	2997998	8095	1804.5	0.2229
	dy030_2lep	28	0.4220E+07	1.3	0.1010	2997999	40867	7553.0	0.1848
	dy081_2lep	29	0.4610E+08	1.3	0.1010	4495998	9981	13437.3	1.3463
	dy100_2lep	30	0.1750E+07	1.3	0.1010	2992000	86668	6655.8	0.0768

Event Weight for 1fb^{-1}

MC Process	ID	σ_{mc}(fb)	K	Br	N_{mc}	N_{precut}	N_{test}	Weight
ww_ee_higgs140	0	0.4132E+03	2.027	0.2500	117800	7943	14.1	0.00178
ww_ee_higgs150	0	0.5122E+03	1.986	0.2500	118400	8629	18.5	0.00215
ww_ee_higgs160	0	0.6003E+03	1.941	0.2500	167600	12755	22.2	0.00174
ww_ee_higgs165	0	0.6056E+03	1.923	0.2500	217100	16827	22.6	0.00134
ww_ee_higgs170	0	0.5804E+03	1.917	0.2500	167200	12995	21.6	0.00166
ww_ee_higgs180	0	0.5107E+03	1.910	0.2500	118700	8810	18.1	0.00205

$$N_{test} = \sigma \cdot K \cdot Br \cdot \frac{N_{precut}}{N_{MC}} \underbrace{\int \mathscr{L} dt}_{1\ \mathrm{fb}^{-1}}$$

events in 1 fb^{-1}

11 beam-days @ 10^{33}

$$Weight = \frac{N_{test}}{N_{preselect}}$$

MC for $H \rightarrow WW \rightarrow \mu\nu\mu\nu$ Analysis

Higgs Signal

SM Background

MC Process	ID	σ_{mc}(fb)	K	Br	N_{mc}	N_{precut}	N_{test}	Weight
ww_mumu_higgs140	0	0.4132E+03	2.027	0.2500	117800	15883	28.2	0.00178
ww_mumu_higgs150	0	0.5122E+03	1.986	0.2500	118400	16179	34.8	0.00215
ww_mumu_higgs160	0	0.6003E+03	1.941	0.2500	167600	23591	41.0	0.00174
ww_mumu_higgs165	0	0.6056E+03	1.923	0.2500	217100	30803	41.3	0.00134
ww_mumu_higgs170	0	0.5804E+03	1.917	0.2500	167200	23160	38.5	0.00166
ww_mumu_higgs180	0	0.5107E+03	1.910	0.2500	118700	15563	32.0	0.00205
ww_mumu	1	0.1133E+06	1.000	0.0120	49000	20944	581.1	0.02775
ttbar	2	0.7590E+06	1.000	0.5550	622000	9994	6768.4	0.67724
WmZ_lnull	3	0.2099E+05	1.000	0.0144	17700	1277	21.8	0.01708
WpZ_lnull	4	0.3673E+05	1.000	0.0144	27000	1795	35.2	0.01959
ZJET010020_2mu	5	0.1360E+08	1.300	0.0336	2936413	83365	16865.1	0.20230
ZJET020040_2mu	6	0.8670E+07	1.300	0.0336	1995792	60959	11567.1	0.18975
ZJET040080_2mu	7	0.4120E+07	1.300	0.0336	1189793	40313	6097.5	0.15125
ZJET080120_2mu	8	0.8270E+06	1.300	0.0336	397856	15437	1401.6	0.09080
ZJET120_2mu	9	0.3830E+06	1.300	0.0336	199832	9372	784.6	0.08372
ZoG030081_2lep	10	0.4220E+07	1.300	0.1010	1000000	80872	44810.0	0.55409
ZoG081100_2lep	11	0.4610E+08	1.300	0.1010	4375998	28345	39207.1	1.38321
ZoG100_2lep	12	0.1750E+07	1.300	0.1010	2872000	211120	16890.7	0.08001
ZZ_llll	13	0.1886E+05	1.000	0.0045	36400	3693	8.6	0.00233
Zgamma_ll	14	0.8910E+06	1.500	0.0672	999742	24097	2164.8	0.08984

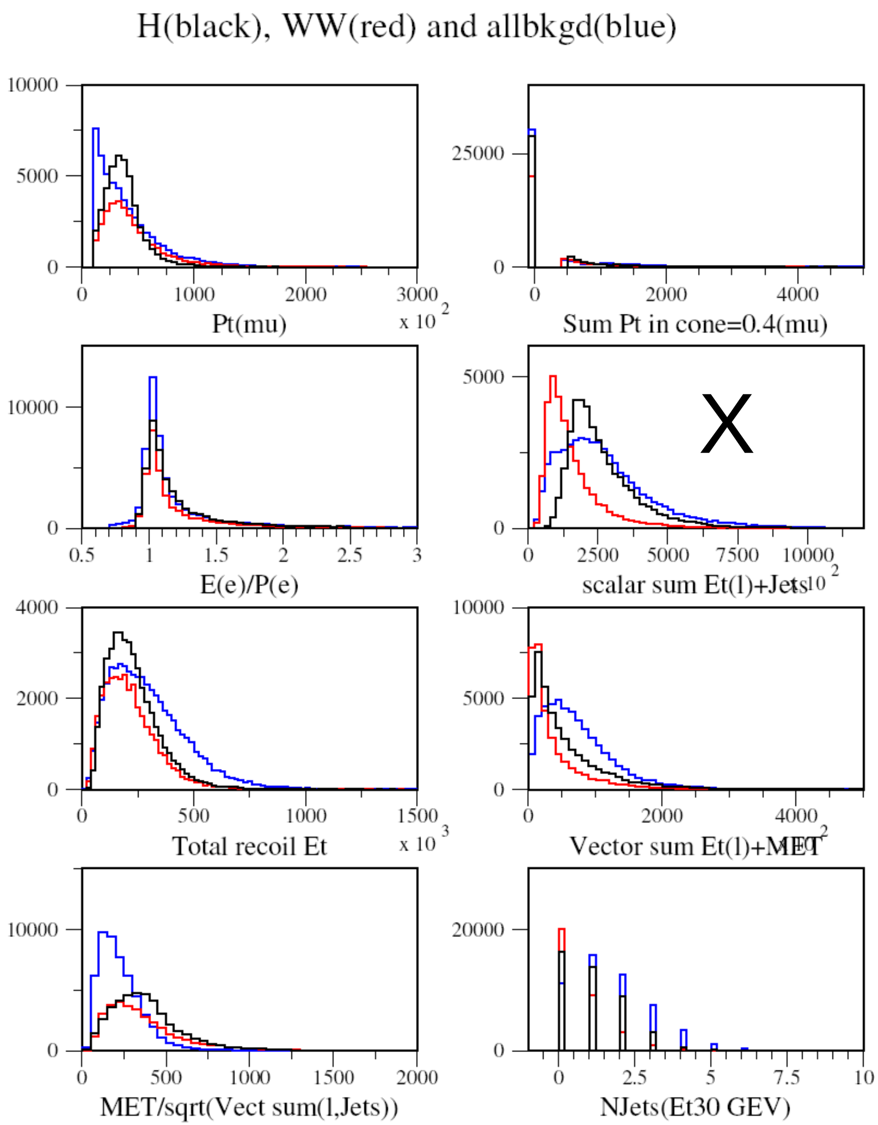
MC for H→WW→eνμν Analysis

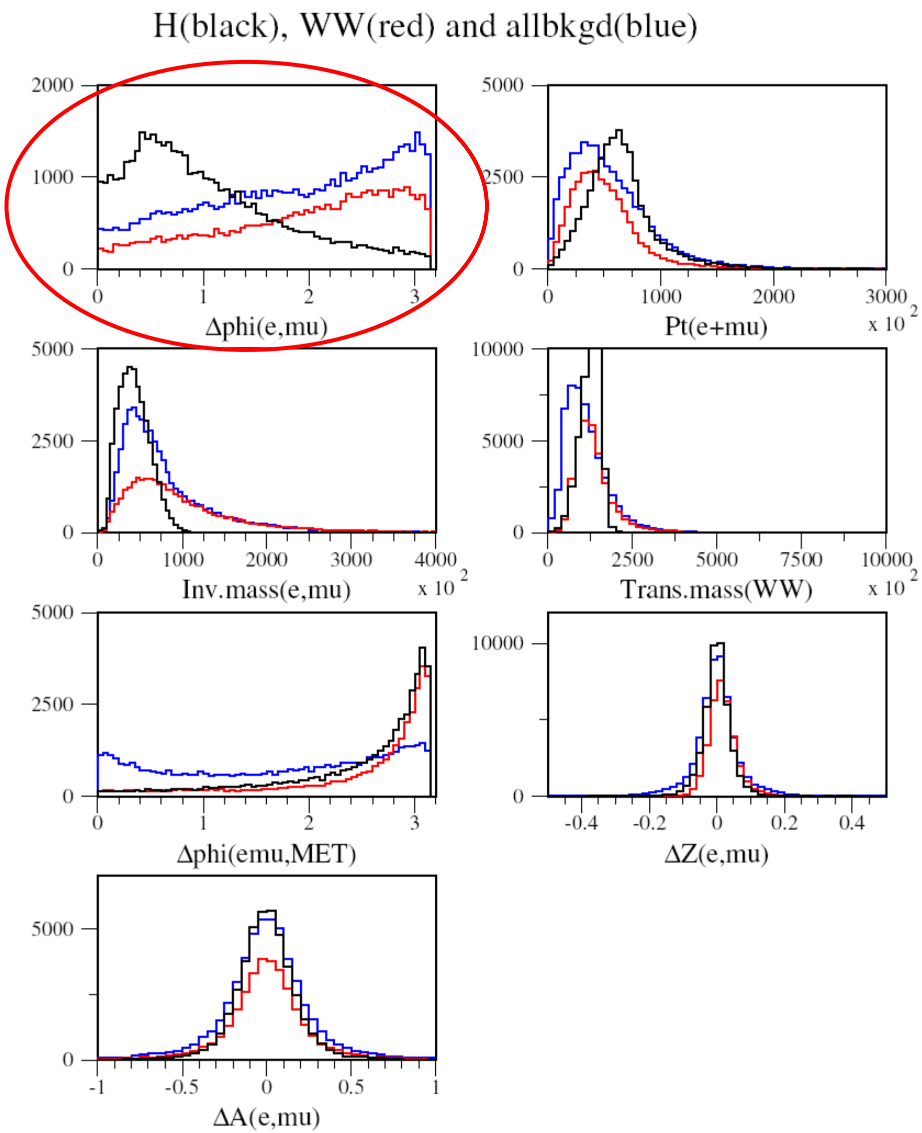
	MC Process	ID	σ_{mc}(fb)	K	Br	N_{mc}	N_{precut}	N_{test}	Weight
Higgs Signal	ww_emu_higgs140	0	0.4132E+03	2.027	0.5000	117800	22987	81.7	0.00355
	ww_emu_higgs150	0	0.5122E+03	1.986	0.5000	118400	24335	104.5	0.00430
	ww_emu_higgs160	0	0.6003E+03	1.941	0.5000	167600	36202	125.8	0.00348
	ww_emu_higgs165	0	0.6056E+03	1.923	0.5000	217100	47557	127.6	0.00268
	ww_emu_higgs170	0	0.5804E+03	1.917	0.5000	167200	37589	125.1	0.00333
	ww_emu_higgs180	0	0.5107E+03	1.910	0.5000	118700	27178	111.7	0.00411
SM Background	ww_emx	1	0.1133E+06	1.0	0.0120	47000	18233	527.0	0.0289
	ww_mex	1	0.1133E+06	1.0	0.0120	48000	18813	532.9	0.0283
	ttbar	2	0.7590E+06	1.0	0.5550	688400	22849	13981.7	0.6119
	ZGamma_ll	3	0.8910E+06	1.5	0.0672	149742	52	31.2	0.5998
	W_enu	4	0.1580E+09	1.3	0.1072	2494958	274	2418.1	8.8254
	W_munu	5	0.1580E+09	1.3	0.1072	1998396	304	3349.6	11.0183
	W_taunu	6	0.1580E+09	1.3	0.1072	2493808	53	468.0	8.8294
	WJET010020_lepnu	7	0.4350E+08	1.3	0.3216	400000	34	1545.9	45.4662
	WJET020040_lepnu	8	0.2680E+08	1.3	0.3216	303000	72	2662.5	36.9787
	WJET040080_lepnu	9	0.1180E+08	1.3	0.3216	300000	123	2022.7	16.4445
	WJET080120_lepnu	10	0.2160E+07	1.3	0.3216	299000	113	341.3	3.0202
	WJET120_lepnu	11	0.9080E+06	1.3	0.3216	296000	85	109.0	1.2825
	ZJET010020_2e	12	0.1360E+08	1.3	0.0336	597281	123	122.3	0.9946
	ZJET020040_2e	13	0.8670E+07	1.3	0.0336	398697	221	209.9	0.9499
	ZJET040080_2e	14	0.4120E+07	1.3	0.0336	397524	468	211.9	0.4527
	ZJET080120_2e	15	0.8270E+06	1.3	0.0336	397009	408	37.1	0.0910
	ZJET120_2e	16	0.3830E+06	1.3	0.0336	198652	157	13.2	0.0842
	ZJET010020_2mu	17	0.1360E+08	1.3	0.0336	597413	491	488.2	0.9944
	ZJET020040_2mu	18	0.8670E+07	1.3	0.0336	396793	489	466.7	0.9544
	ZJET040080_2mu	19	0.4120E+07	1.3	0.0336	776793	1365	316.2	0.2317
	ZJET080120_2mu	20	0.8270E+06	1.3	0.0336	396856	813	74.0	0.0910
	ZJET120_2mu	21	0.3830E+06	1.3	0.0336	194832	638	54.8	0.0859
	ZJET010020_2tau	22	0.1360E+08	1.3	0.0336	598783	1883	1868.1	0.9921
	ZJET020040_2tau	23	0.8670E+07	1.3	0.0336	399076	1688	1601.8	0.9490
	ZJET040080_2tau	24	0.4120E+07	1.3	0.0336	398972	2487	1121.8	0.4511
	ZJET080120_2tau	25	0.8270E+06	1.3	0.0336	396671	3582	326.2	0.0911
	ZJET120_2tau	26	0.3830E+06	1.3	0.0336	199046	2984	250.8	0.0840
	ZoG030081_2lep	27	0.4220E+07	1.3	0.1010	599000	160	148.0	0.9250
	ZoG081100_2lep	28	0.4610E+08	1.3	0.1010	499000	649	7872.4	12.1301
	ZoG100_2lep	29	0.1750E+07	1.3	0.1010	493000	1145	533.7	0.4661
	WGamma_lnu	30	0.1420E+07	1.0	0.2144	1996438	462	70.5	0.1525
	WGamma_taunu	31	0.1420E+07	1.0	0.1072	687999	30	6.6	0.2213
	WpZ_lnull.v11004206	32	0.3673E+05	1.0	0.0144	27000	4815	94.3	0.0196
	WmZ_lnull.v11004206	33	0.2099E+05	1.0	0.0144	17700	3537	60.4	0.0171
	ZZ_llll.v11004206	34	0.1886E+05	1.0	0.0045	36400	5341	12.5	0.0023

BDT Training Variables

- Sum P_t in cone=0.4(μ)
- E(e)/P(e)
- scalar sum E_t(l)+Jets
- Total recoil E_t
- Vector sum E_t(l)+MET
- MET/sqrt(Vect sum(l,Jets))
- NJets(E_t >30 GeV)
- $\Delta\phi(e,\mu)$
- $P_t(e+\mu)$
- Inv.mass(e,μ)
- Trans.mass(WW)
- $\Delta\phi(e\mu, MET)$
- $\Delta Z(e,\mu)$
- $\Delta A(e,\mu)$

Signal vs Background





Boosted Decision Trees (BDT)

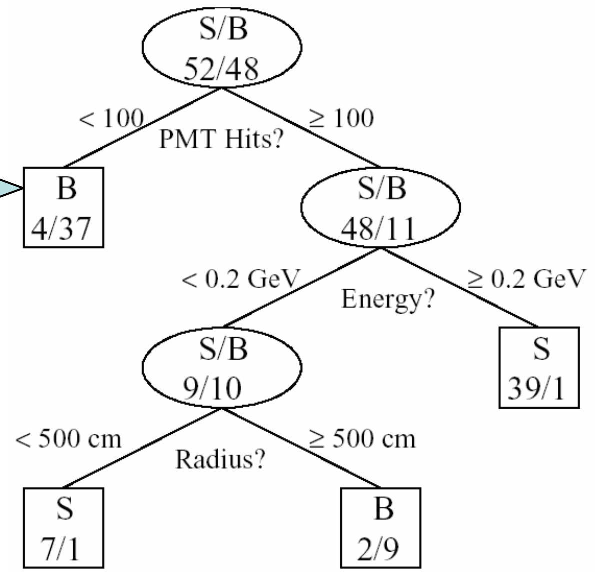
How to build a decision tree ?

For each node, try to find the best variable and splitting point which gives the best separation based on Gini index.

Gini_node = Weight_total*P*(1-P), P is weighted purity

Criterion = Gini_father – Gini_left_son – Gini_right_son

Variable is selected as splitter by maximizing the criterion.

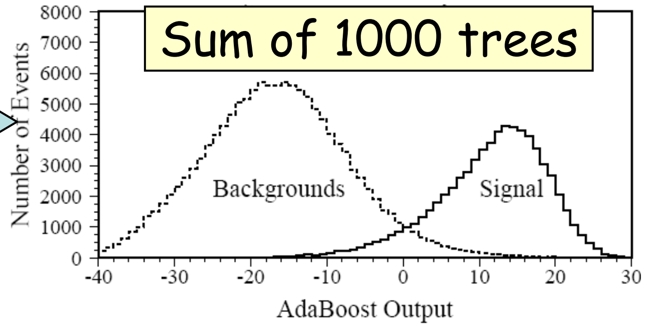


How to boost the decision trees?

Weights of misclassified events in current tree are increased, the next tree is built using the same events but with new weights. Typically, one may build few hundred to thousand trees.

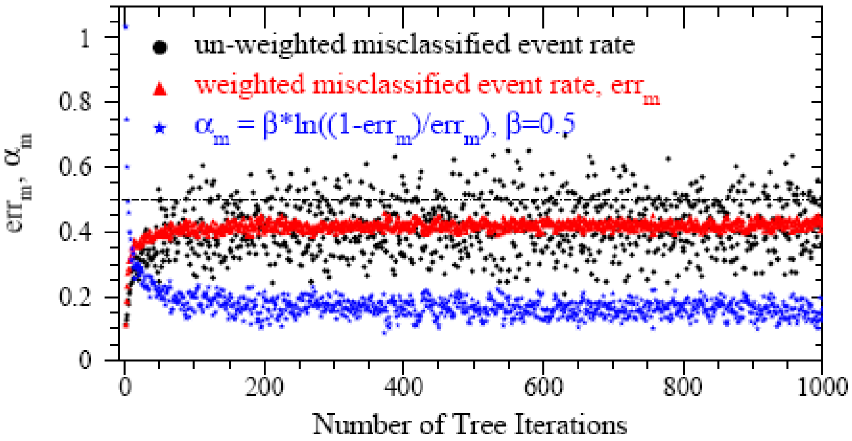
How to calculate the event score ?

For a given event, if it lands on the signal leaf in one tree, it is given a score of 1, otherwise, -1. The sum (probably weighted) of scores from all trees is the final score of the event.



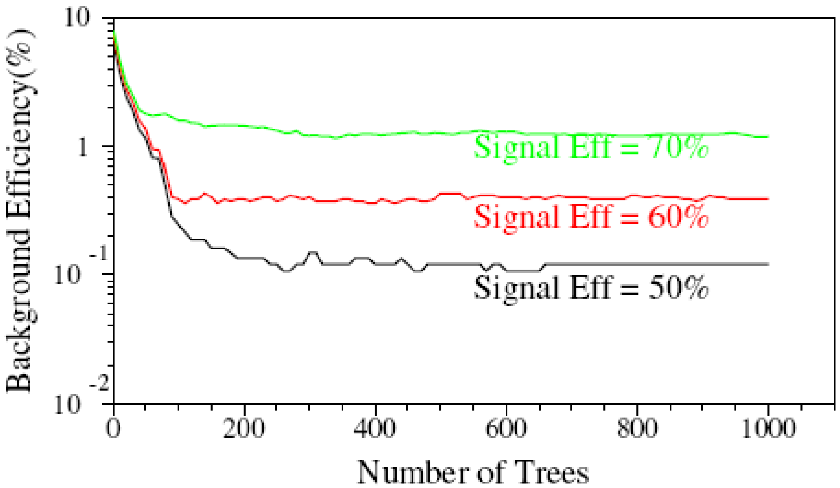
Ref: B.P. Roe, H.J. Yang, J. Zhu, Y. Liu, I. Stancu, G. McGregor, "*Boosted decision trees as an alternative to artificial neural networks for particle identification*", physics/0408124, NIM A543 (2005) 577-584.

Weak → Powerful Classifier



→ The advantage of using boosted decision trees is that it combines many decision trees, “weak” classifiers, to make a powerful classifier. The performance of boosted decision trees is stable after a few hundred tree iterations.

→ Boosted decision trees focus on the misclassified events which usually have high weights after hundreds of tree iterations. An individual tree has a very weak discriminating power; the weighted misclassified event rate err_m is about 0.4-0.45.



Ref1: H.J.Yang, B.P. Roe, J. Zhu, “*Studies of Boosted Decision Trees for MiniBooNE Particle Identification*”, physics/0508045, Nucl. Instum. & Meth. A 555(2005) 370-385.

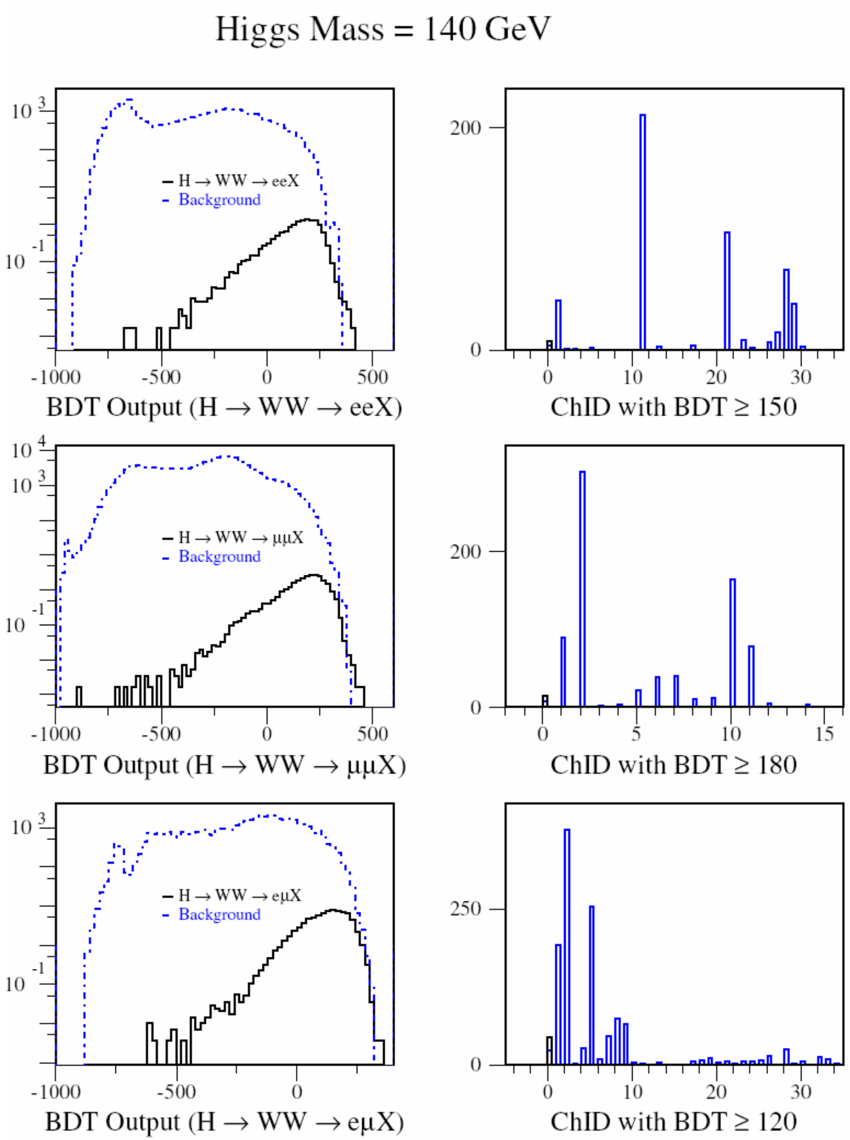
Ref2: H.J. Yang, B. P. Roe, J. Zhu, " *Studies of Stability and Robustness for Artificial Neural Networks and Boosted Decision Trees* ", physics/0610276, Nucl. Instrum. & Meth. A574 (2007) 342-349.

BDT Training with Event Reweighting

- In the original BDT training program, all training events are set to have same weights in the beginning (the first tree). It works fine if all MC processes are produced based on their production rates.
- Our MCs are produced separately, the event weights vary from various backgrounds. e.g. assuming 1 fb^{-1} wt (WW) = 0.029, wt (ttbar) = 0.61, wt(DY) = 12.1
- If we treat all training events with different weights equally using "standard" training algorithm, ANN/BDT tend to pay more attention to events with lower weights (high stat.) and introduce training prejudice.

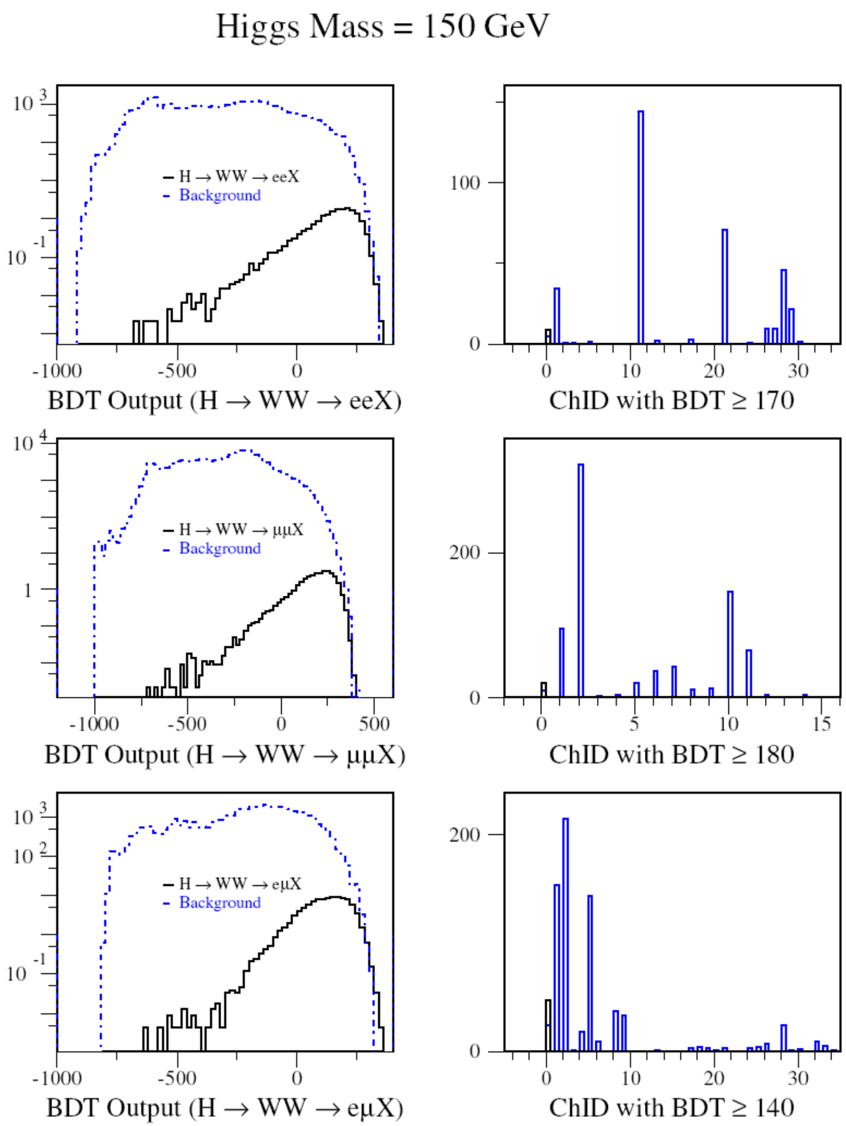
- Ref: http://arxiv.org/abs/0708.3635, Hai-Jun Yang, Tiesheng Dai, Alan Wilson, Zhengguo Zhao, Bing Zhou, "A Multivariate Training Technique with Event Reweighting"

Higgs Mass = 140 GeV



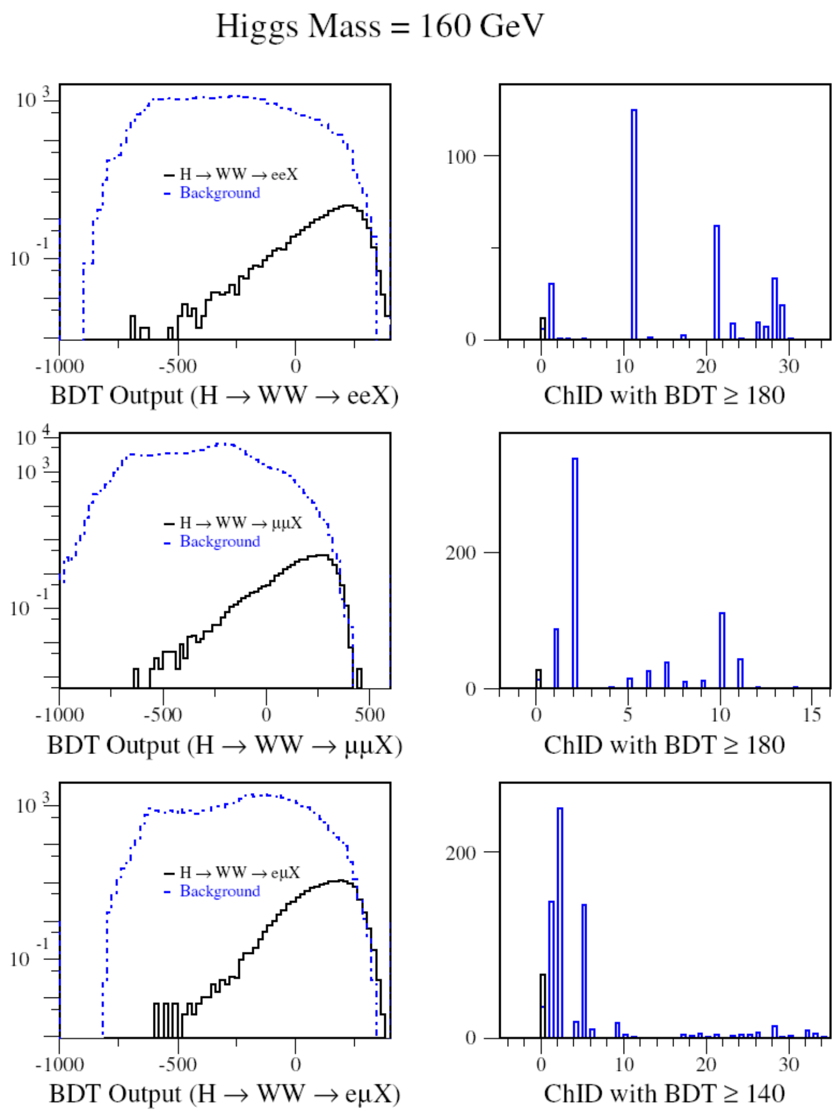
Higgs mass = 140 GeV			
Analysis Channels	BDT Bins	N_{signal}	N_{bkgd}
$H \to WW \to eeX$	150-200	3.26	372.26
$H \to WW \to eeX$	200-250	3.08	134.25
$H \to WW \to eeX$	≥ 250	1.49	20.29
$H \to WW \to eeX$	≥ 150	7.83	526.80
$H \to WW \to \mu\mu X$	180-220	5.19	513.13
$H \to WW \to \mu\mu X$	220-280	7.16	222.73
$H \to WW \to \mu\mu X$	≥ 280	3.26	31.80
$H \to WW \to \mu\mu X$	≥ 180	15.61	767.66
$H \to WW \to e\mu X$	120-150	10.44	484.60
$H \to WW \to e\mu X$	150-200	18.67	538.90
$H \to WW \to e\mu X$	200-240	10.80	113.18
$H \to WW \to e\mu X$	≥ 240	3.59	9.56
$H \to WW \to e\mu X$	≥ 120	43.50	1146.24
$H \to WW \to \ell\ell X$	All Bins	66.94	2440.70
Major Background	eeX	$\mu\mu X$	$e\mu X$
WW	52.5	89.2	192.6
$t\bar{t}$	212.0	301.4	376.9
$W \to e\nu$	105.9	-	26.5
$W \to \mu\nu$	-	-	253.4
Drell-Yan	140.7	245.4	26.1
WJet	-	-	189.5
Total Background	526.8	767.7	1146.2

Higgs Mass = 150 GeV



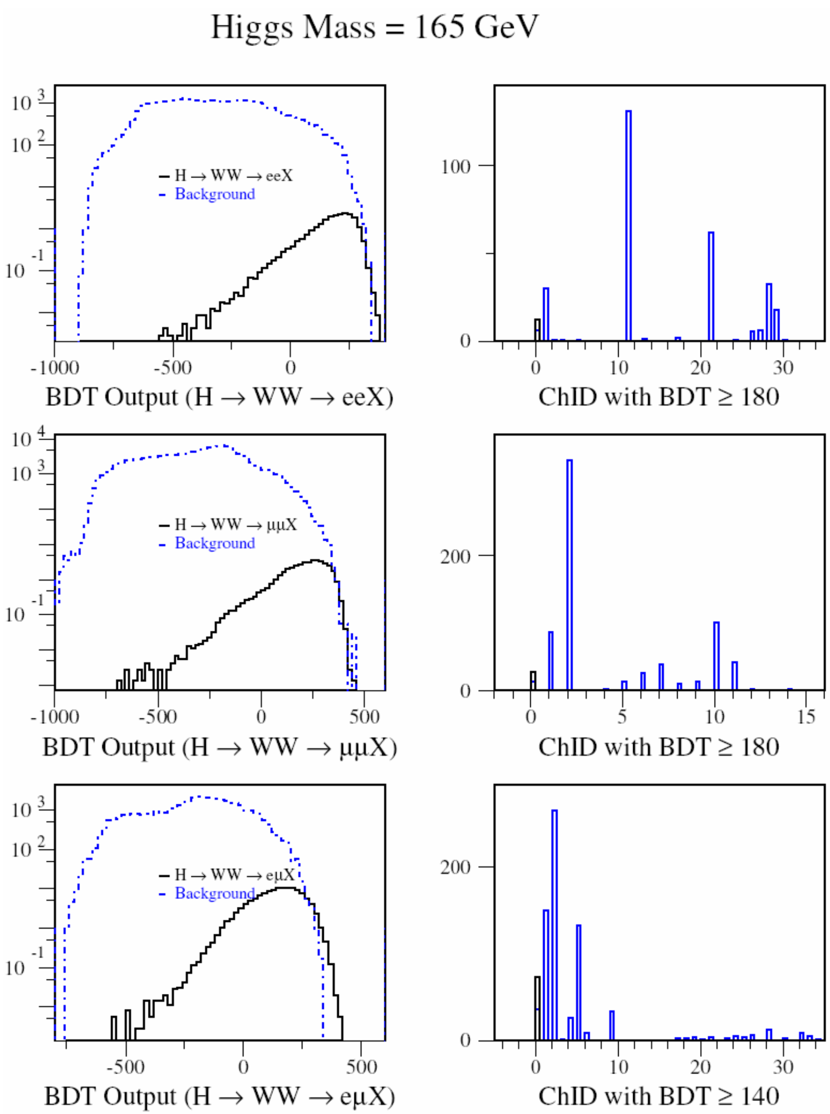
Higgs mass = 150 GeV			
Analysis Channels	BDT Bins	N_{signal}	N_{bkgd}
$H \to WW \to eeX$	170-200	2.68	208.76
$H \to WW \to eeX$	200-250	4.29	124.26
$H \to WW \to eeX$	≥250	2.03	13.18
$H \to WW \to eeX$	≥170	9.00	346.20
$H \to WW \to \mu\mu X$	180-220	5.66	489.54
$H \to WW \to \mu\mu X$	220-280	9.22	236.33
$H \to WW \to \mu\mu X$	≥280	4.91	37.75
$H \to WW \to \mu\mu X$	≥180	19.78	763.62
$H \to WW \to e\mu X$	140-180	18.33	462.70
$H \to WW \to e\mu X$	180-220	16.56	177.03
$H \to WW \to e\mu X$	220-250	8.04	33.77
$H \to WW \to e\mu X$	≥250	3.93	7.63
$H \to WW \to e\mu X$	≥140	46.87	681.13
$H \to WW \to \ell\ell X$	All Bins	75.65	1790.95
Major Background	eeX	$\mu\mu X$	$e\mu X$
WW	39.7	95.6	153.0
$t\bar{t}$	144.3	321.0	214.8
$W \to e\nu$	70.6	-	17.7
$W \to \mu\nu$	-	-	143.2
Drell-Yan	87.5	214.7	25.2
WJet	-	-	70.1
Total Background	346.2	763.6	681.1

Higgs Mass = 160 GeV



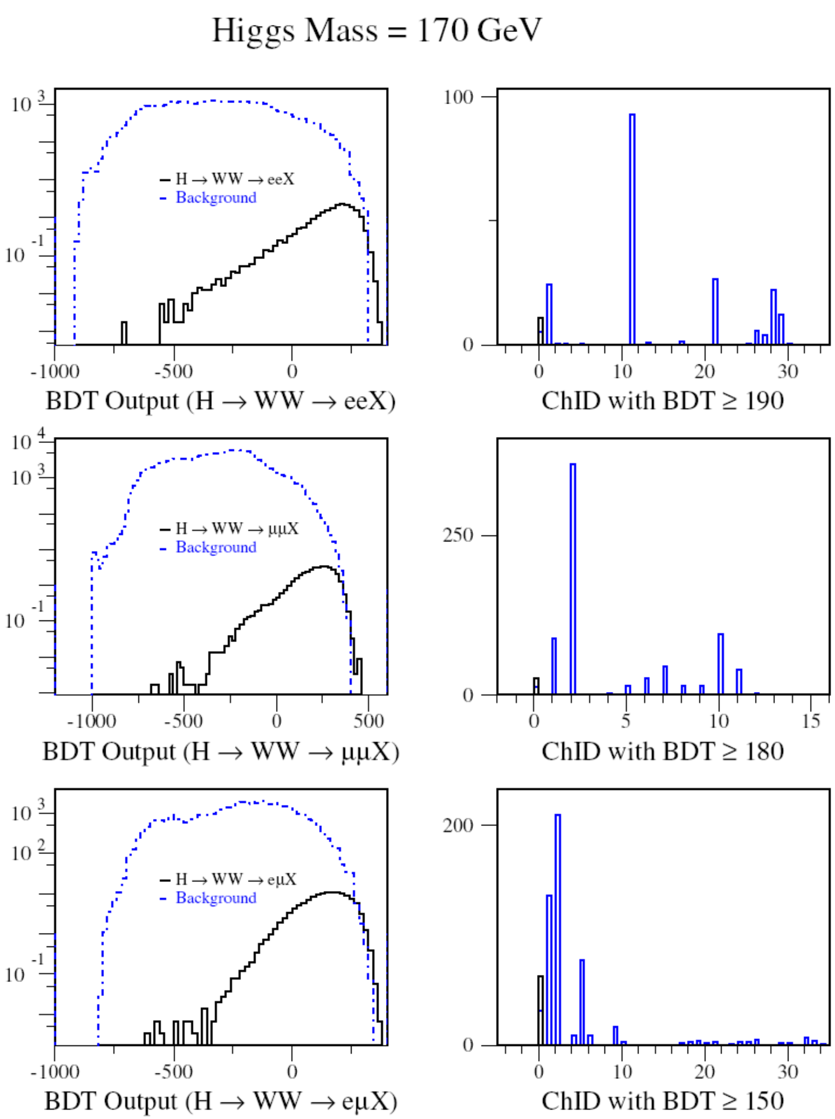
Higgs mass = 160 GeV			
Analysis Channels	BDT Bins	N_{signal}	N_{bkgd}
$H \to WW \to eeX$	180-220	4.15	210.83
$H \to WW \to eeX$	220-280	5.61	85.75
$H \to WW \to eeX$	≥280	1.77	5.89
$H \to WW \to eeX$	≥180	11.53	302.47
$H \to WW \to \mu\mu X$	180-220	5.96	409.00
$H \to WW \to \mu\mu X$	220-280	10.50	229.24
$H \to WW \to \mu\mu X$	≥280	9.43	50.47
$H \to WW \to \mu\mu X$	≥180	25.89	688.71
$H \to WW \to e\mu X$	140-180	21.20	394.13
$H \to WW \to e\mu X$	180-220	21.60	198.28
$H \to WW \to e\mu X$	220-250	13.47	42.60
$H \to WW \to e\mu X$	≥250	9.30	9.25
$H \to WW \to e\mu X$	≥140	65.57	644.26
$H \to WW \to \ell\ell X$	All Bins	102.99	1635.44
Major Background	eeX	$\mu\mu X$	$e\mu X$
WW	34.4	87.8	147.4
$t\bar{t}$	125.3	337.3	247.8
$W \to e\nu$	61.8	-	17.7
$W \to \mu\nu$	-	-	143.2
Drell-Yan	69.3	155.7	13.0
WJet	-	-	20.8
Total Background	302.5	688.7	644.3

Higgs Mass = 165 GeV



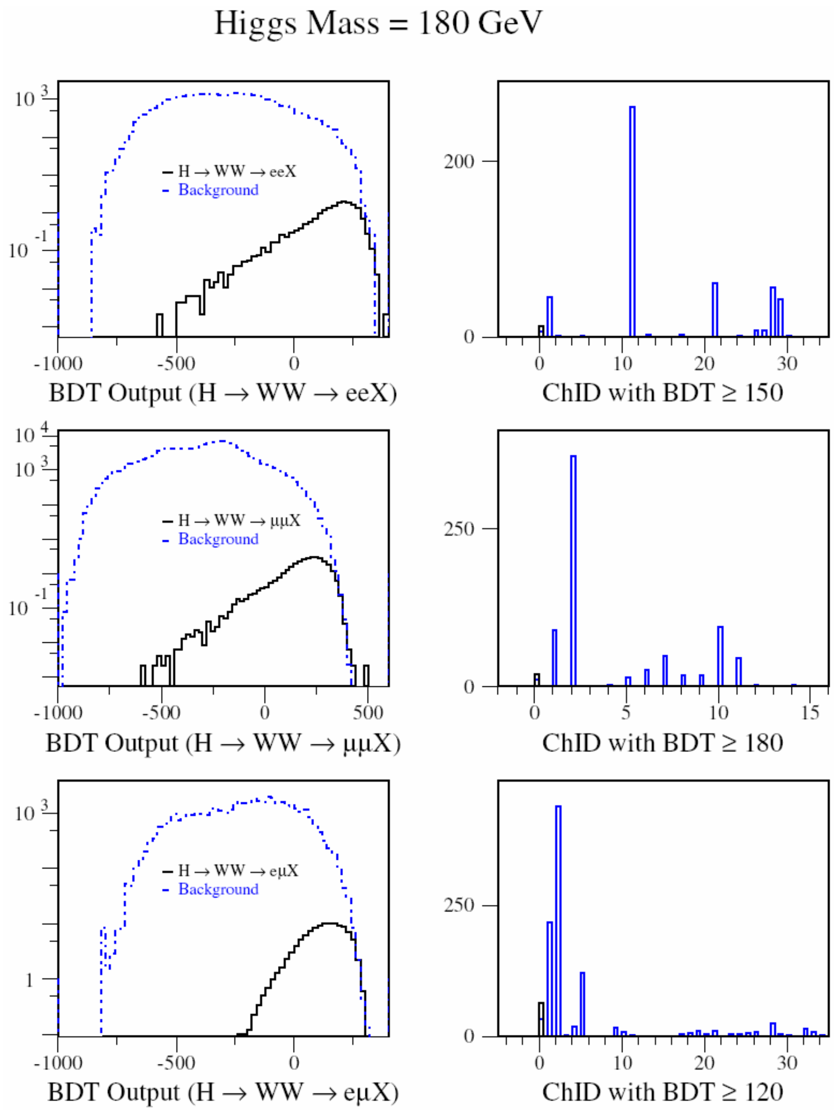
Higgs mass = 165 GeV			
Analysis Channels	BDT Bins	N_{signal}	N_{bkgd}
$H \to WW \to eeX$	180-220	4.21	201.00
$H \to WW \to eeX$	220-280	6.25	85.25
$H \to WW \to eeX$	$\geq$280	1.69	6.20
$H \to WW \to eeX$	$\geq$180	12.15	292.45
$H \to WW \to \mu\mu X$	180-220	5.67	398.88
$H \to WW \to \mu\mu X$	220-280	9.86	233.45
$H \to WW \to \mu\mu X$	$\geq$280	11.29	62.04
$H \to WW \to \mu\mu X$	$\geq$180	26.83	694.37
$H \to WW \to e\mu X$	140-180	20.19	397.80
$H \to WW \to e\mu X$	180-220	20.35	195.90
$H \to WW \to e\mu X$	220-250	12.56	68.60
$H \to WW \to e\mu X$	$\geq$250	16.88	15.80
$H \to WW \to e\mu X$	$\geq$140	69.98	678.10
$H \to WW \to \ell\ell X$	All Bins	108.96	1664.92
Major Background	eeX	$\mu\mu X$	$e\mu X$
WW	33.8	86.1	149.9
$t\bar{t}$	131.4	341.3	265.0
$W \to e\nu$	61.7	-	26.5
$W \to \mu\nu$	-	-	132.2
Drell-Yan	62.7	145.2	12.6
WJet	-	-	33.2
Total Background	292.5	694.4	678.1

Higgs Mass = 170 GeV



Higgs mass = 170 GeV			
Analysis Channels	BDT Bins	N_{signal}	N_{bkgd}
$H \to WW \to eeX$	190-220	3.30	101.96
$H \to WW \to eeX$	220-280	5.41	85.32
$H \to WW \to eeX$	≥280	1.55	4.95
$H \to WW \to eeX$	≥190	10.26	192.23
$H \to WW \to \mu\mu X$	180-220	5.71	423.29
$H \to WW \to \mu\mu X$	220-280	9.47	232.28
$H \to WW \to \mu\mu X$	≥280	9.51	51.10
$H \to WW \to \mu\mu X$	≥180	24.69	706.67
$H \to WW \to e\mu X$	150-180	15.16	237.67
$H \to WW \to e\mu X$	180-220	19.40	186.93
$H \to WW \to e\mu X$	220-260	15.70	68.22
$H \to WW \to e\mu X$	≥260	10.18	8.33
$H \to WW \to e\mu X$	≥150	60.44	501.15
$H \to WW \to \ell\ell X$	All Bins	95.39	1400.05
Major Background	eeX	$\mu\mu X$	$e\mu X$
WW	26.9	88.5	135.9
$t\bar{t}$	92.8	360.3	209.9
$W \to e\nu$	26.5	-	8.8
$W \to \mu\nu$	-	-	77.1
Drell-Yan	44.4	137.0	1.4
WJet	-	-	19.6
Total Background	192.2	706.7	501.2

Higgs Mass = 180 GeV



Higgs mass = 180 GeV			
Analysis Channels	BDT Bins	N_{signal}	N_{bkgd}
$H \to WW \to eeX$	150-200	3.86	329.59
$H \to WW \to eeX$	200-250	4.37	140.00
$H \to WW \to eeX$	≥250	3.11	25.25
$H \to WW \to eeX$	≥150	11.35	494.84
$H \to WW \to \mu\mu X$	180-220	5.12	446.90
$H \to WW \to \mu\mu X$	220-280	8.54	239.73
$H \to WW \to \mu\mu X$	≥280	6.00	40.13
$H \to WW \to \mu\mu X$	≥180	19.65	726.76
$H \to WW \to e\mu X$	140-180	19.71	421.46
$H \to WW \to e\mu X$	180-220	17.61	147.45
$H \to WW \to e\mu X$	220-250	9.87	34.03
$H \to WW \to e\mu X$	≥250	4.76	6.60
$H \to WW \to e\mu X$	≥140	51.95	609.54
$H \to WW \to \ell\ell X$	All Bins	82.95	1831.14
Major Background	eeX	$\mu\mu X$	$e\mu X$
WW	50.9	89.7	165.7
$t\bar{t}$	262.1	363.7	246.6
$W \to e\nu$	61.7	-	17.7
$W \to \mu\nu$	-	-	88.2
Drell-Yan	115.7	141.6	14.0
WJet	-	-	23.9
Total Background	494.8	726.8	609.5

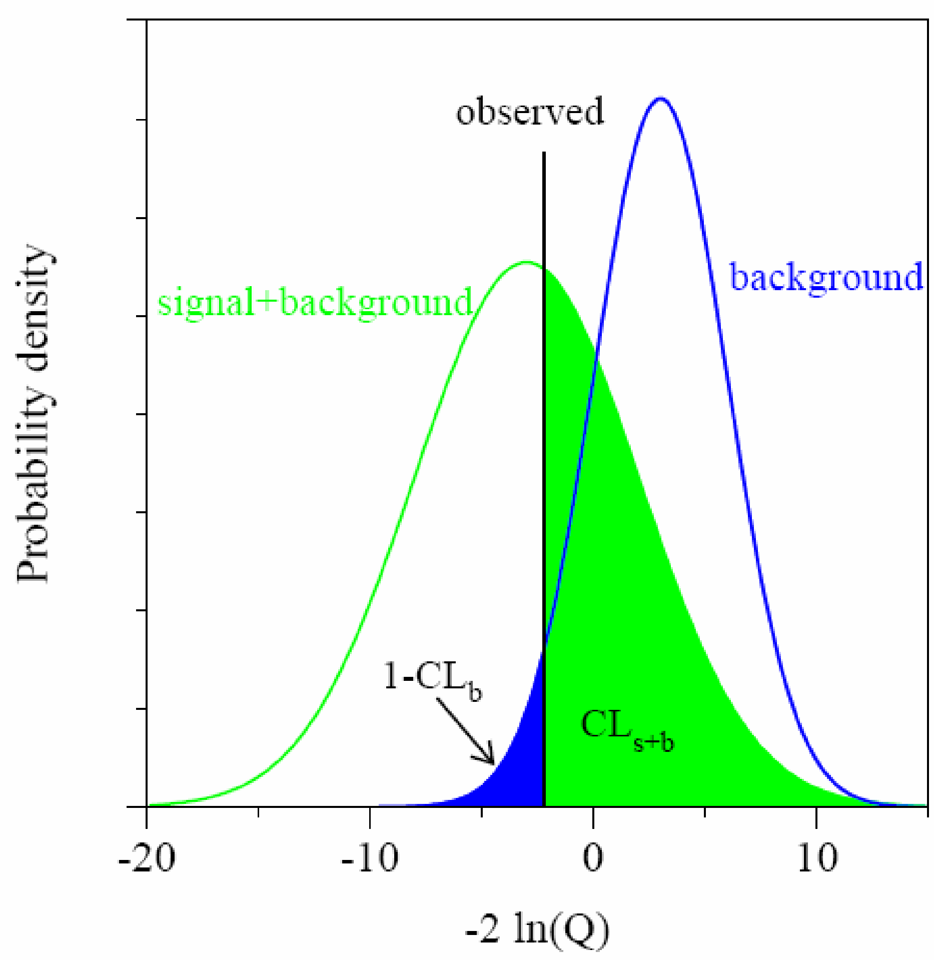
Confidence Level Calculation

➔ Log-likelihood ratio test-statistics using 10 BDT bins

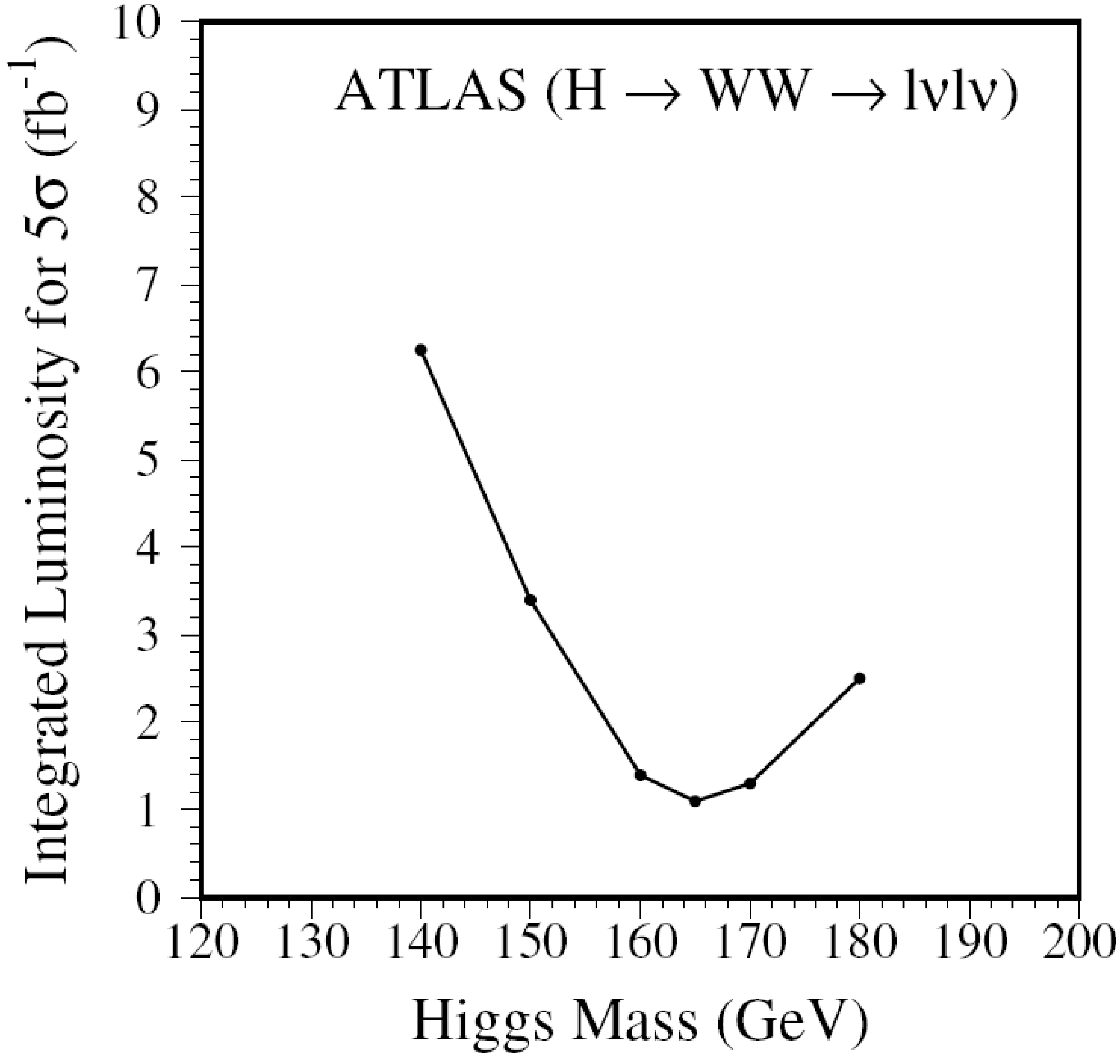
$$Q = \frac{L(s+b)}{L(b)}$$

➔ MC experiments are based on Poisson statistics

➔ CL_b represents C.L. to exclude "background only" hypothesis



Sensitivity of H → WW → lνlν



Summary

- H → WW → lνlν analysis based on BDT
- For 165 GeV Higgs, 5 sigma discovery can be achieved using about 1.1 fb^{-1} data.
- Major backgrounds for H → WW searches come from ttbar(40%-50%), WW(10%-20%), Drell-Yan(20%-30%), W→ lν (15%-20%)
- Additional BDTs trained with Higgs signal against major backgrounds may help to further suppress background and improve sensitivity.

Backup Slides

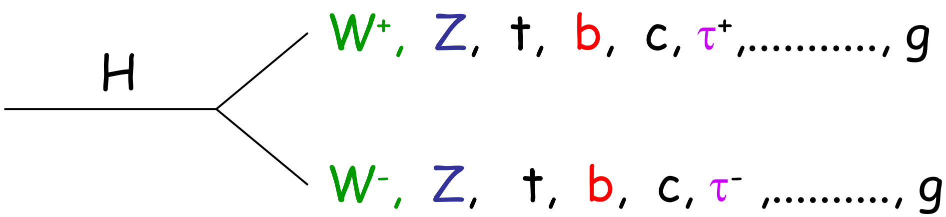
BDT Free Software

- http://gallatin.physics.lsa.umich.edu/~hyang/boosting.tar.gz

- TMVA toolkit, CERN Root
  http://tmva.sourceforge.net/
  http://root.cern.ch/root/html/src/TMVA__MethodBDT.cxx.html

Properties of the Higgs Boson

The decay properties of the Higgs boson are fixed,
if the mass is known:



$$\Gamma(H \to f\bar{f}) \;=\; N_C \frac{G_F}{4\sqrt{2}\pi}\, m_f^2(M_H^2)\, M_H$$

$$\Gamma(H \to VV) \;= \delta_V \frac{G_F}{16\sqrt{2}\pi}\, M_H^3\, (1 - 4x + 12x^2)\, \beta_V$$

where: $\delta_Z = 1, \delta_W = 2, \quad x = M_V^2/M_V^2, \quad \beta =$ velocity

$$\Gamma(H \to gg) \;= \frac{G_F\ \alpha_s^2(M_H^2)}{36\sqrt{2}\pi^3}\, M_H^3\, \left[1 + \left(\frac{95}{4} - \frac{7N_f}{6}\right)\frac{\alpha_s}{\pi}\right]$$

$$\Gamma(H \to \gamma\gamma) \;= \frac{G_F\ \alpha^2}{128\sqrt{2}\pi^3}\, M_H^3\, \left[\frac{4}{3} N_C e_t^2 - 7\right]^2$$

Higgs Boson:

- it couples to particles proportional to their masses
- decays preferentially in the heaviest particles kinematically allowed