Discovery Potential of the SM Higgs Through H→WW Decay Mode at LHC with the ATLAS Detector

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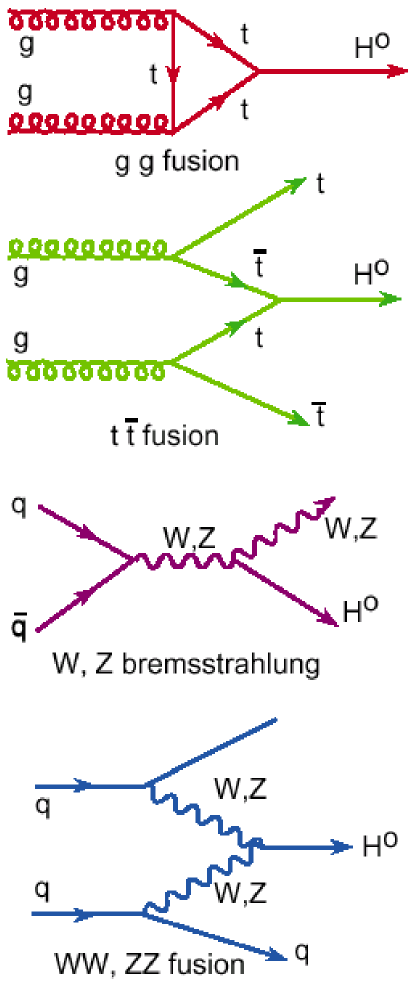
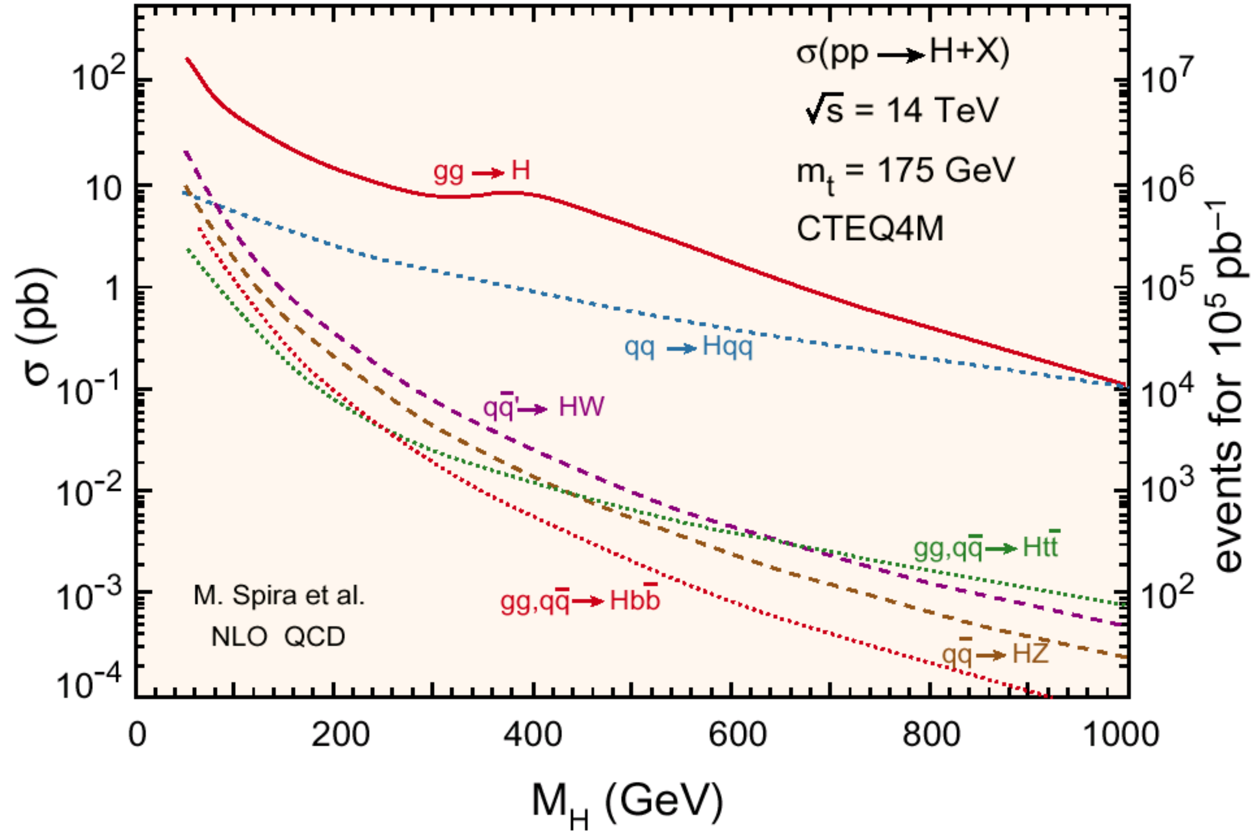
Outline

- Introduction
- Current limits on the SM Higgs searches
- The ATLAS Detector
- $H \rightarrow WW$ signatures
- Results from cut-based analysis
- Signal detection improvement by using multivariate method (Boosted Decision Trees)
- Conclusions

SM Higgs Production at LHC





➔ Gluon-gluon fusion and WW/ZZ fusion are two dominant Higgs production mechanism.

Higgs Decay Branching Ratios and Discovery Channels

Low mass region: $m(H) < 2\,m_Z$

$H \to \gamma\gamma$ (good at mH ~ 120 GeV)

$H \to bb$ (huge bb background)

$H \to \tau\tau$

$H \to ZZ^* \to 4\ell$ (clean)

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

$m(H) > 2\,m_Z$

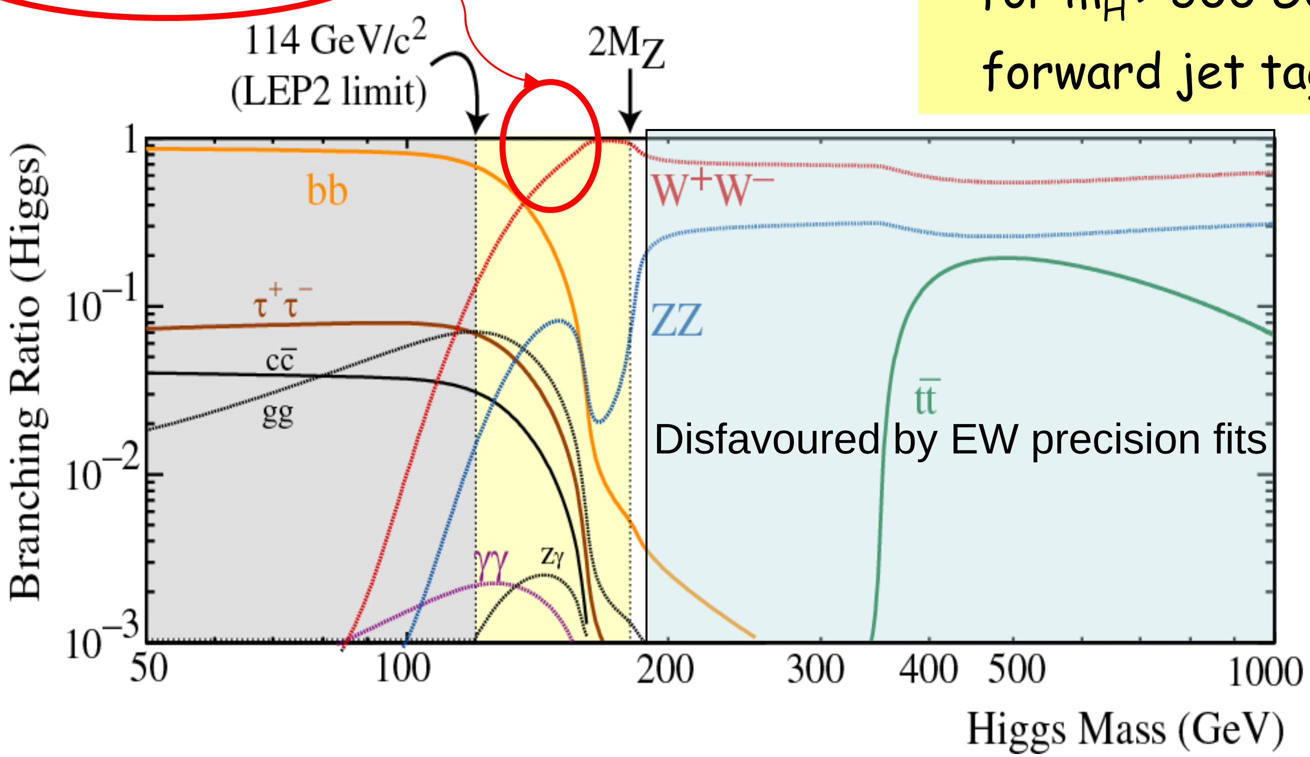
$H \to ZZ \to 4\ell$

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

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

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

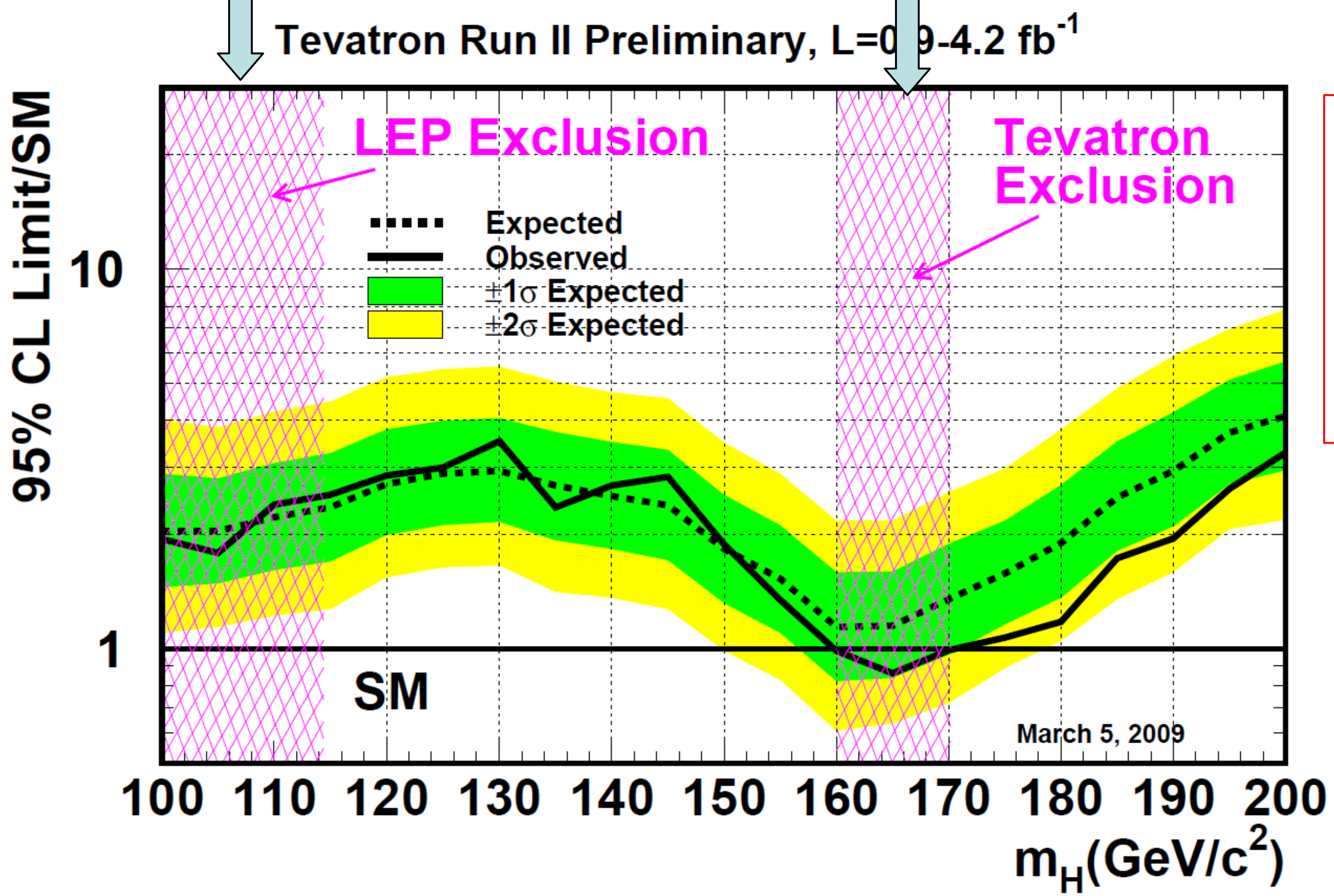
* for $m_H > 300$ GeV forward jet tag



Present Limits on Higgs Searches

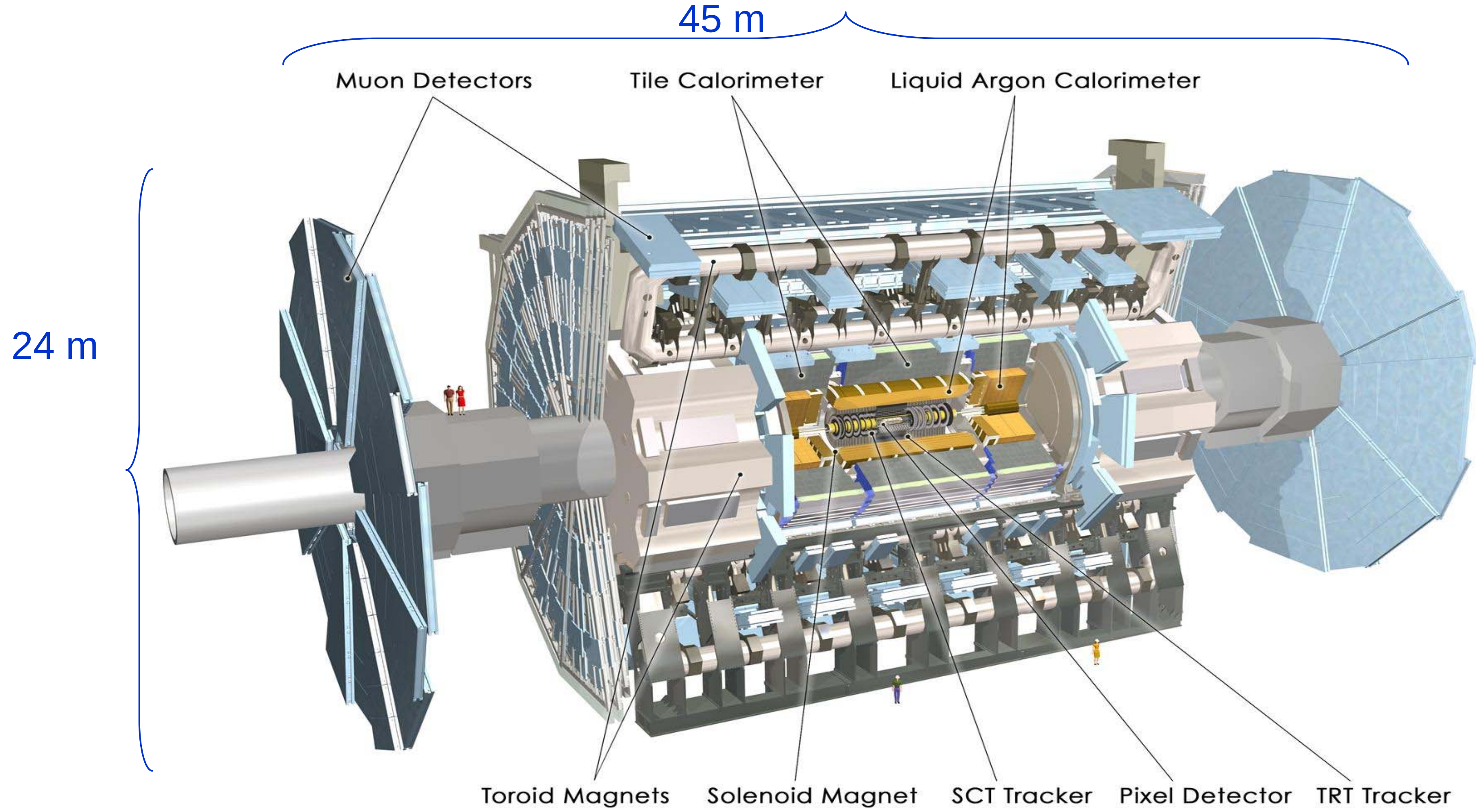
LEP direct search: m_H > 114.4 GeV
http://lepewwg.web.cern.ch/LEPEWWG

Recent CDF+DO direct search ($4.2 fb^{-1}$) exclude range 160 -170 GeV
http://arxiv.org/abs/0903.4001



Experiments at LHC will cover the whole mass range for SM Higgs search

The ATLAS Detector at LHC



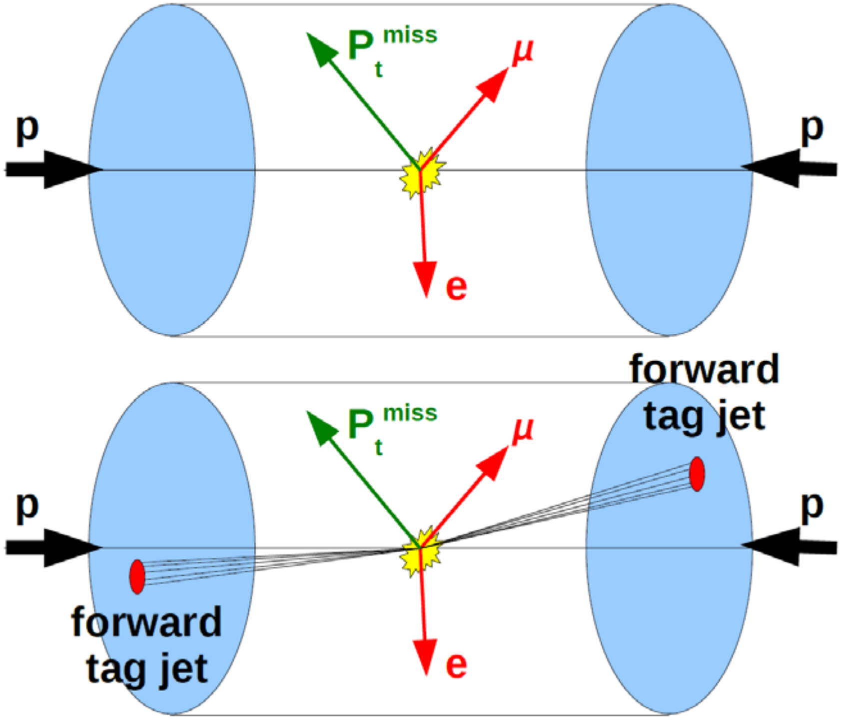
ATLAS Collaboration, JINST 3:S08003 (2008)

Search for H→WW using leptonic decay final states at LHC

- **Main search channel for mass in range: 130 GeV < m_H < 190 GeV due to large WW decay branching ratio**

- **Analyses:**
  - **H + 0 jets → lvlv (dominated by Gluon Gluon Fusion)**
  - **H + 2 jets → lvlv + 2 jets (dominated by Vector Boson Fusion)**

- **Main backgrounds: WW, Wt, tt and W+jets**



Signal and Background cross sections at $\sqrt{s}$ = 14 TeV

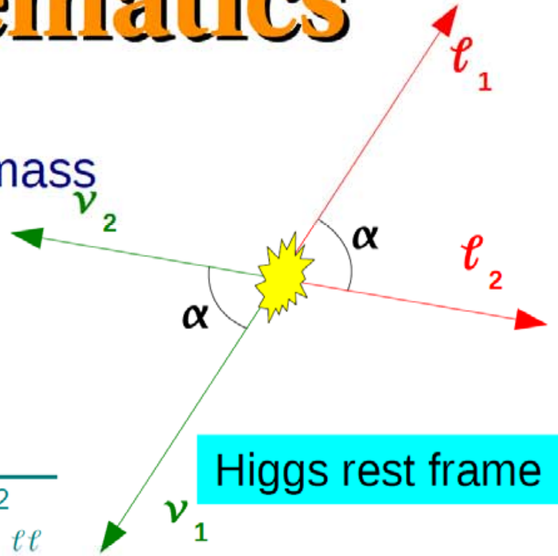
Process	Generator	Cross-section(pb)
$gg \to H \to WW$ ($M_H = 170$ GeV)	MC@NLO	19.418
VBF $H \to WW$ ($M_H = 170$ GeV)	PYTHIA/Sherpa	2.853
VBF $H \to WW$ ($M_H = 300$ GeV)	HERWIG	0.936
$qq/qg \to WW$	MC@NLO/Alpgen	111.6
$gg \to WW$	GG2WW	5.26
$pp \to t\bar{t}$	MC@NLO	833
$Z \to \tau\tau$+jets	PYTHIA/ALPGEN	2015
W+jets	ALPGEN	20510

BR(W→ eν) = 10.8%, cross section of H → WW → lνlν (l=e,μ) at m_H = 170 GeV and 14 TeV center-of-mass energy is 0.906 pb.

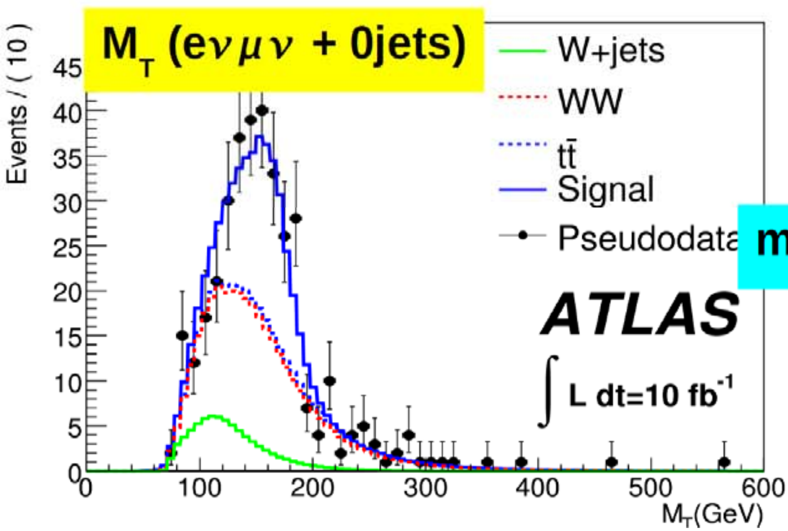
Major experimental challenges:

- **Irreducible SM WW background**
- **Unable to reconstruct M_H in leptonic decay modes**

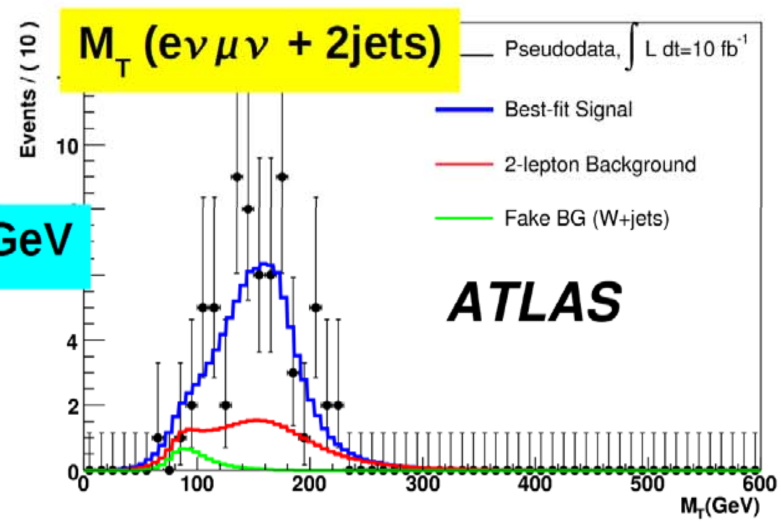
$H \to W^{(*)}W \to e\nu\mu\nu$: kinematics



- 2 neutrinos ⇒ 6 unknowns ⇒ cannot reconstruct Higgs mass
- Use "**transverse mass**":
  - $M_T = \sqrt{(E_{T,\ell\ell}+E_T^{miss})^2 - (\vec{p}_{T,\ell\ell}+\vec{p}_T^{miss})^2}$
  - where:
    - $E_{T,\ell\ell} = \sqrt{(p_{T,\ell\ell})^2 + m^2_{\ell\ell}}$; $E_T^{miss} \approx \sqrt{(p_T^{miss})^2 + m^2_{\ell\ell}}$
  - [if $m_H<2m_Z$, $m^2_{\ell\ell} \approx m^2_{\nu\nu}$: both W's almost at rest in Higgs rest frame]

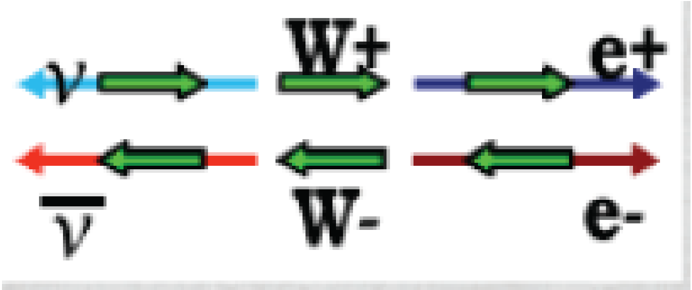


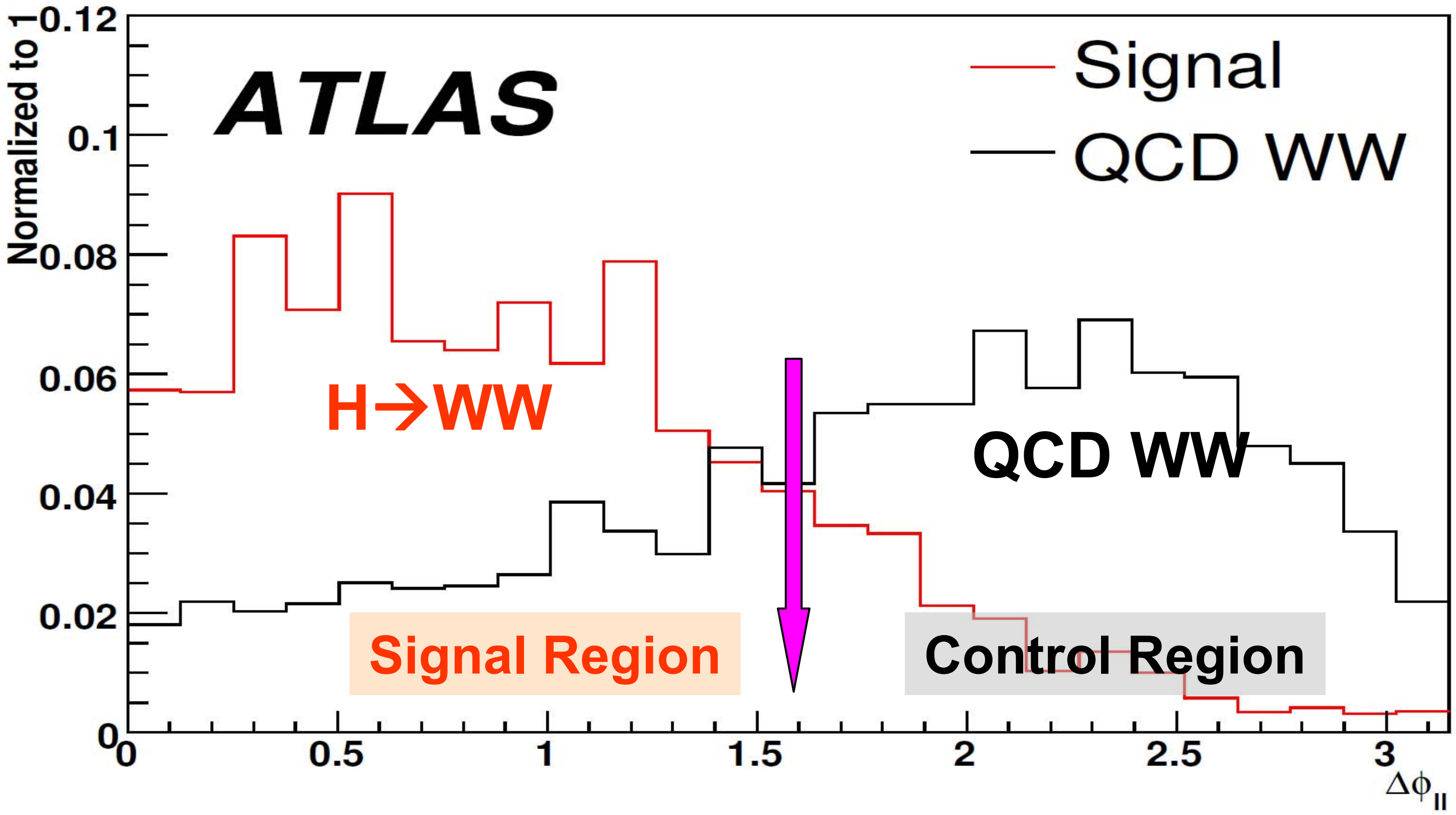
m_H = 170 GeV



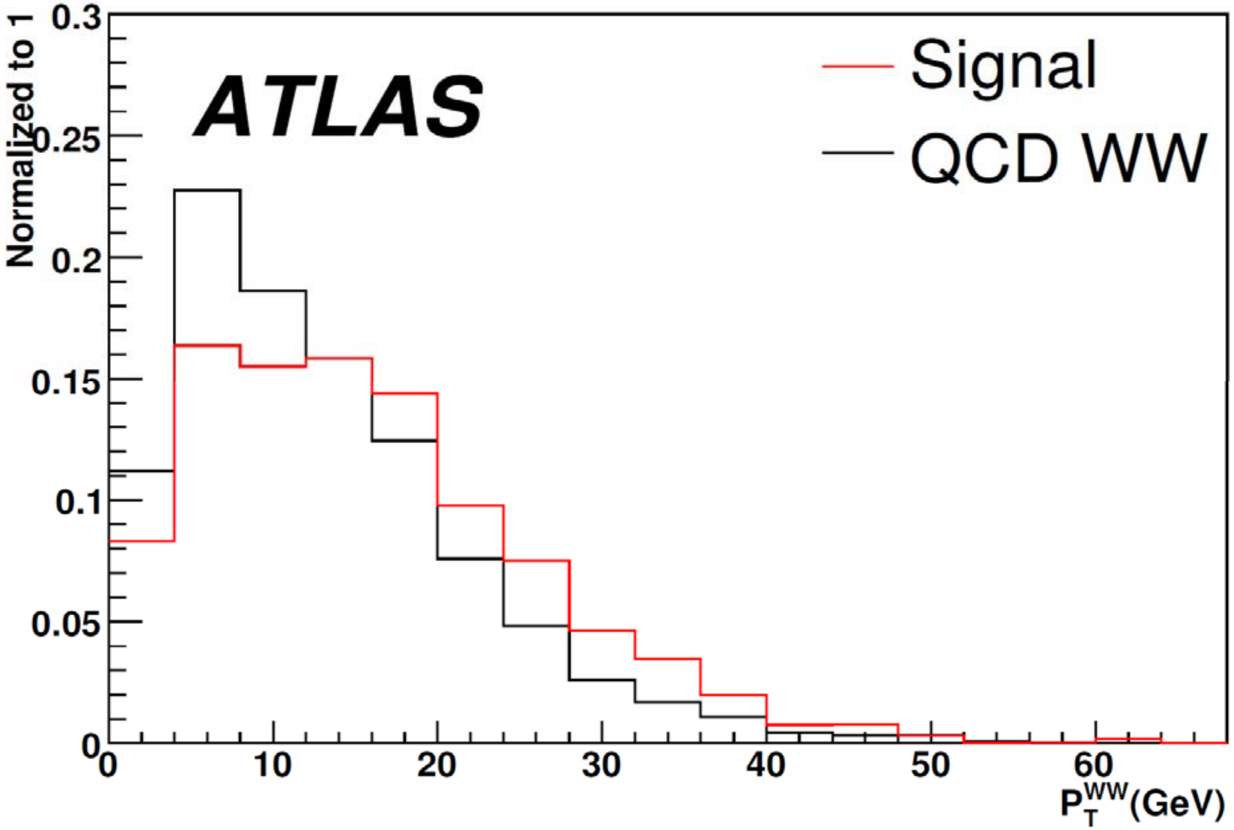
H → WW Signature

Transverse opening angle $\Delta\phi_{ll}$ of two leptons from WW decay





Transverse Momentum of WW



ggF H→WW signal has larger P_T^{WW} than SM WW background because gluon-initiated process tends to have more ISR than quark-initiated process.

Gluon-gluon Fusion H→WW→eνμν Event Selection (m_H=170 GeV, 1 fb^{-1})

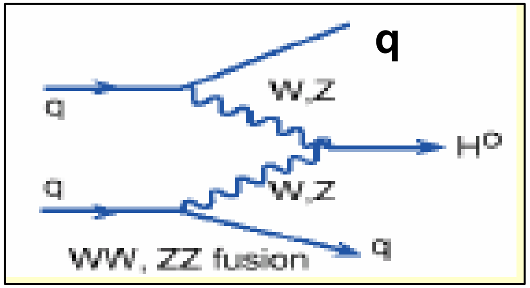
➔ Selected event has exactly two isolated, opposite-charge leptons with p_T>15 GeV

Selection	Selection cuts	$gg \to H$	$t\bar{t}$	WW	$Z \to \tau\tau$	$W + jets$
pre-selection	Lepton Selection+M_{ll}	166.4	6501	718.12	4171	209.1
	$p_T^{miss} > 30$ GeV	147.7	5617	505.25	526.3	181.6
	$Z \to \tau\tau$ Rej.	145.8	5215	485.12	164.2	150.4
	Jet Veto	61.80	14.84	238.35	31.91	76.12
	b-veto	61.56	6.85	237.87	30.76	76.12
signal region	$\Delta\phi_{ll} < 1.575$, $M_T < 600$ GeV	50.6±2.5	2.3±1.6	85.4±2.7	<1.7	38±38
control region	$\Delta\phi_{ll} > 1.575$, $M_T < 600$ GeV	10.9±1.1	4.6±2.3	151.9±3.6	30.8±4.2	38±38
b-tagged signal region	$\Delta\phi_{ll} < 1.575$	-	1.14±1.14	-	-	-
b-tagged control region	$\Delta\phi_{ll} > 1.575$	-	5.71±2.55	-	-	-

➔ **In '*signal region*': 51 Higgs events, 126 background events**

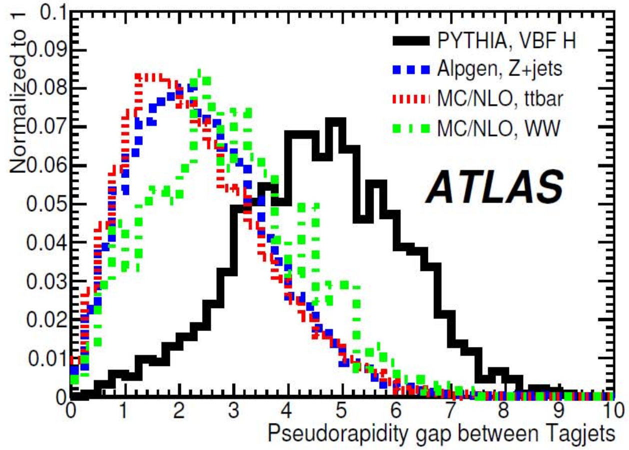
➔**The signal efficiency is 11.2%, signal-to-background ratio is 0.4**

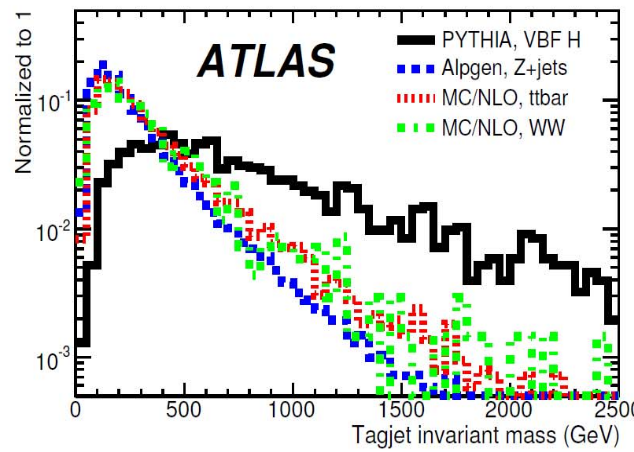
Vector Boson Fusion (VBF) Higgs Production



Signal: WW + 2 jets

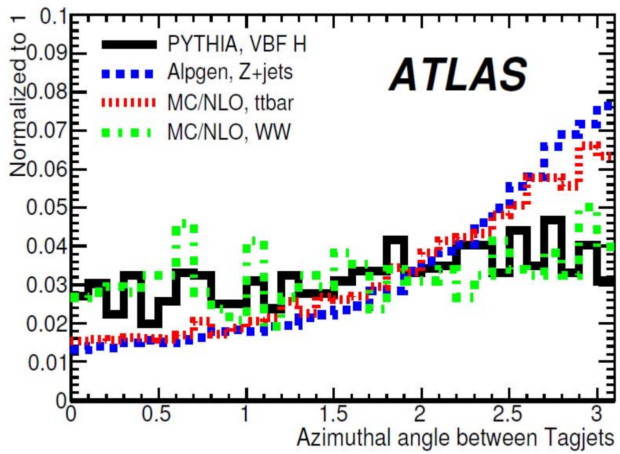
$\Delta\eta_{jj}$

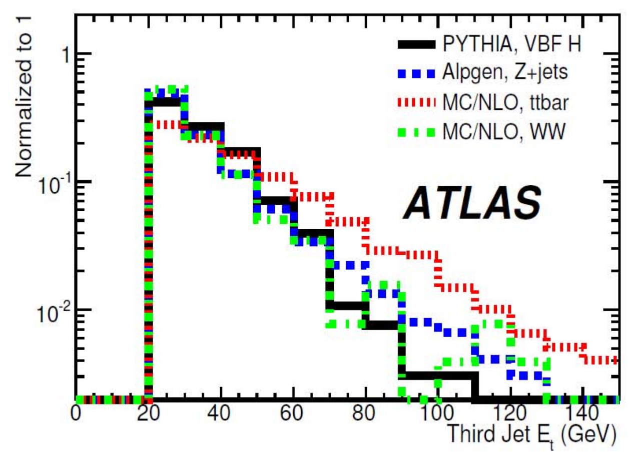




M_{jj}

$\Delta\phi_{jj}$





E_T^{jet3}

VBF H → WW → $e\nu\mu\nu$ + 2 jets Event Selection (m_H=170 GeV, 1 fb^{-1})

Cut	Signal (170 GeV)	$t\bar{t}$	WW+jets	$Z \to \tau\tau$	W+jets
Lepton Selection	30.20	8317	838.96	(2096)	1323
Forward Jet Tagging	17.27	946.6	32.77	79.30	31.83
Leptons Between Jets	16.47	617.8	22.92	55.13	27.91
$Z \to \tau\tau$ Rejection	15.68	561.8	21.20	39.03	27.91
p_T^{miss}, M_T, $m_T^{ll\nu}$	12.78	425.9	15.28	0	13.96
b-veto	12.67	206.72	-	-	-
signal box, b-jet Veto	9.28±0.27	28.5±5.7	4.75±0.30	-	4.3±4.3
signal box, no b-jet Veto	9.65	114.2	4.99	-	6.07
Control, b-jet Veto	3.02±0.15	89±10	9.78±0.43	-	7.9±5.0
Control, no b-jet Veto	3.13	311.7	10.28	-	7.89

Signal box: $\Delta\phi_{ll}$ < 1.5 and $\Delta\eta_{ll}$ < 1.4; otherwise ***Control box***

→ **In signal box with b-veto: 9.3 Higgs events, 38 background events**

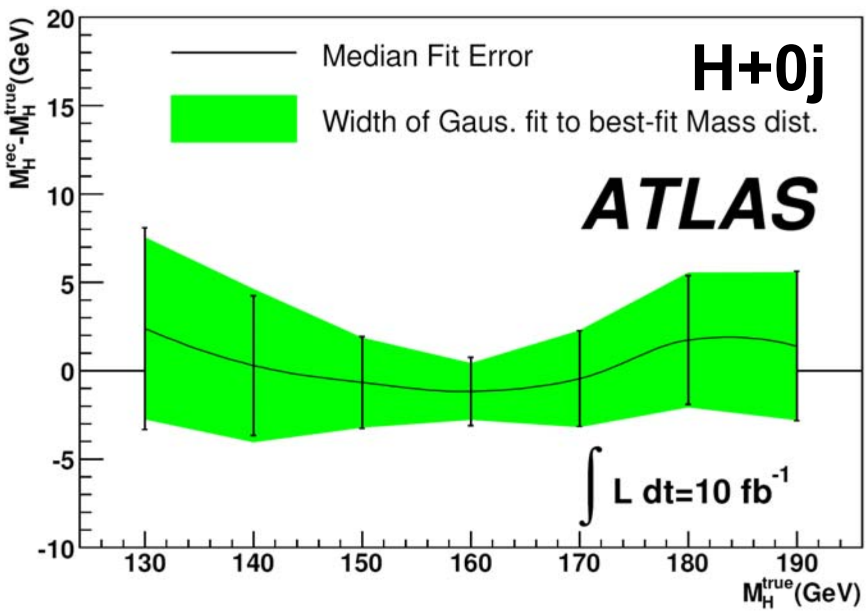
→ **signal efficiency is 7%, signal-to-background ratio is ~0.24**

Higgs Mass Determination (Maximum-likelihood fit)

H→WW→eνμν + 0 jet

2-D fit: M_T and p_T^{WW}

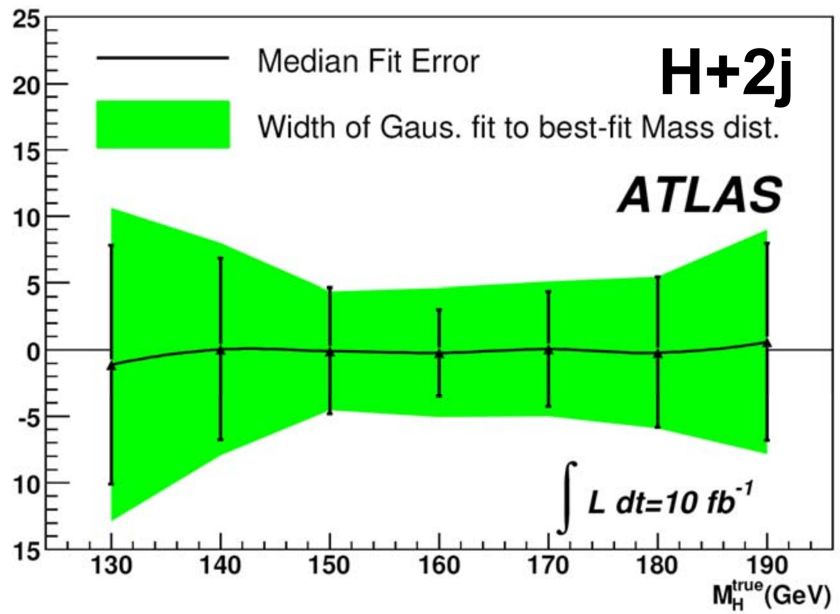
(2bins: $\Delta\phi_{ll}<1.575$, $\Delta\phi_{ll}>1.575$)



H→WW→eνμν + 2 jets

2-D fit: M_T and NN output

($\Delta\eta_{jj}$, M_{jj}, E_T^{jet3}, $\eta_3-(\eta_1+\eta_2)/2$)



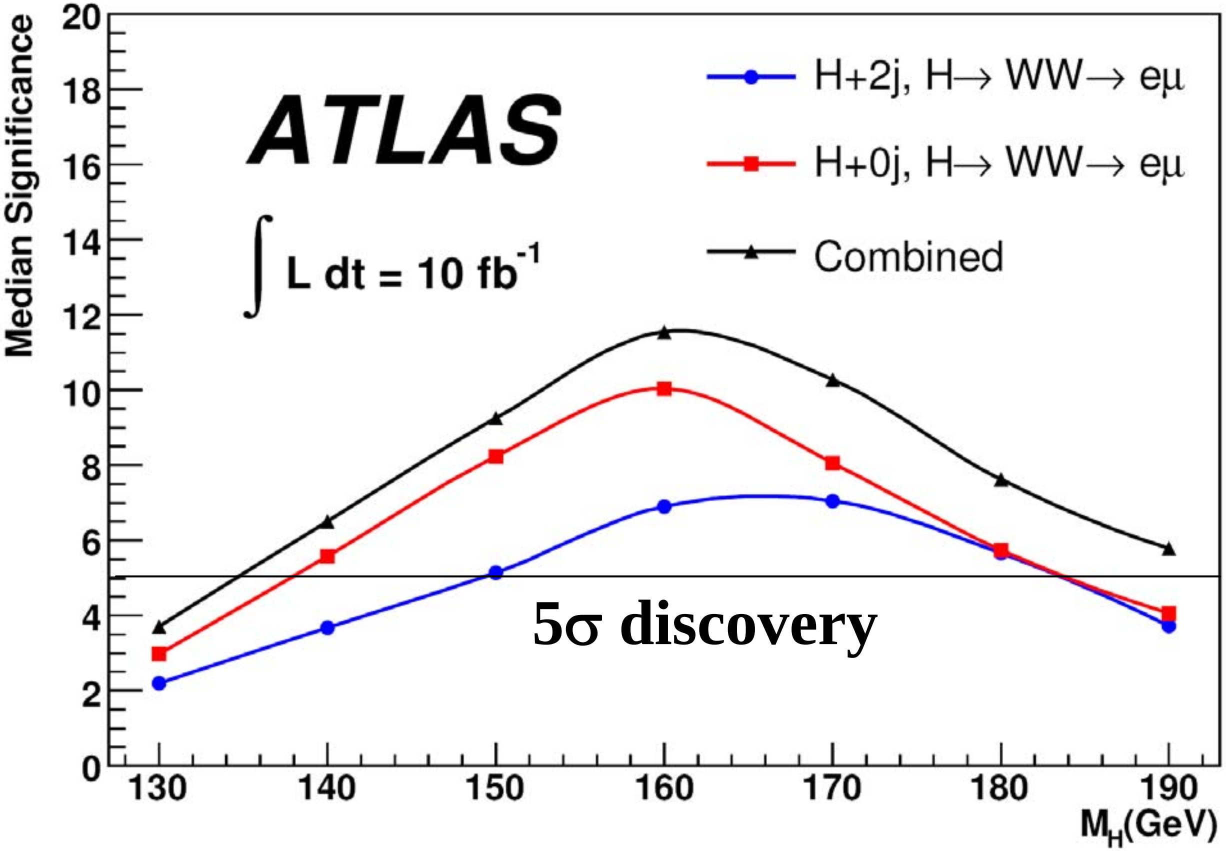
→Higgs mass determination variabilities for 130, 160 and 190 GeV Higgs boson masses are about 5.2, 1.6 and 4.2 GeV, respectively.

Higgs Detection Significance

➔Log-likelihood ratio test-statistics by using M_T, p_T^{WW}, NN distributions in signal and control regions from H + 0/2 jets.

Significance at 10 fb^{-1} for H→WW($e\nu\mu\nu$)+0/2j

5σ discovery could be achieved if Higgs mass between 135 GeV and 190 GeV



To improve the Higgs detection sensitivity

- Using multivariate method (Boosted Decision Trees, ref: H. Yang et.al., NIM A555 (2005) 370) to combine a set of discriminating variables into one final powerful discriminator variable to select Higgs events.

- Discriminating variables used in our BDT analysis:
  - Event topology: Jet multiplicity, Impact parameter of leptons, opening angle between leptons (jets) etc.
  - Energy and momentum of leptons, jets, MET
  - Masses: invariant mass of two leptons, transverse mass of two leptons with MET
  - Lepton isolations: number of tracks, sum of track P_T, sum of jet E_T in $\Delta R < 0.4$ cone around lepton

➔Higgs signal efficiency could be improved by ~30% and signal-to-background ratio is improved by a factor of ~ 2.

Conclusions

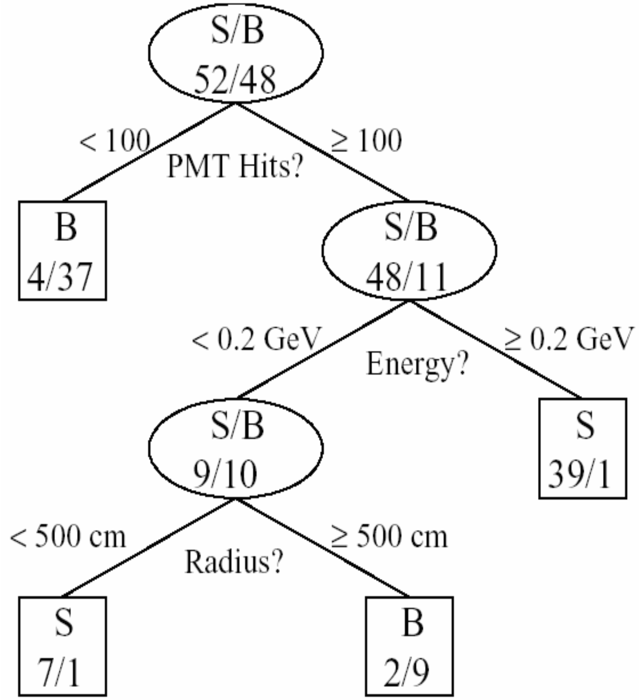
- $H \rightarrow WW \rightarrow l\nu l\nu$ is one of the most interesting and sensitive channels to discover the Higgs boson for Higgs mass between 130 GeV – 190 GeV.
- The Higgs detection sensitivity can be improved significantly by using multivariate method such as Boosted Decision Trees.
- The discovery of the SM Higgs boson through W-pair leptonic decay modes could be achieved by using a few fb^{-1} integrated luminosity if the Higgs mass is around 140 GeV – 190 GeV.

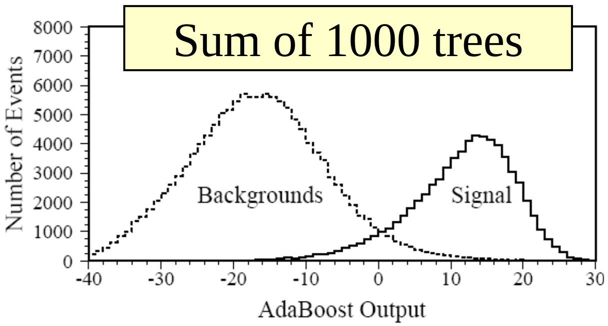
We are looking forward the LHC collision data !

Backup Slides

Boosted Decision Trees (BDT)

➔Relative new in HEP – MiniBooNE, BaBar, D0(single top discovery), ATLAS
➔Advantages: robust, understand 'powerful' variables, 'not a black box', …



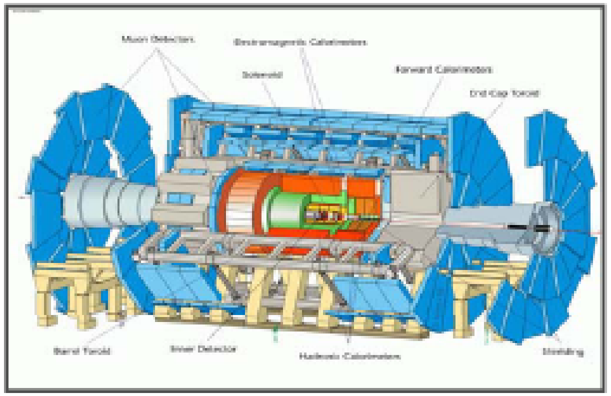


- Split data recursively based on input variables until a stopping criterion is reached (e.g. purity, too few events)
- Every event ends up in a "signal" or a "background" leaf
- Misclassified events will be given larger weight in the next tree (boosting)
- For a given event, if it lands on the signal leaf in one tree, it is given a score of 1, otherwise, -1. The sum of scores from all trees is the final score of the event.

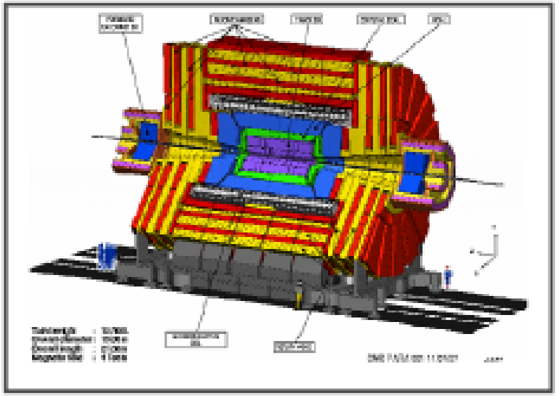
B.P. Roe, H.J. Yang, et.al., physics/0408124, NIM A543 (2005) 577
H.J. Yang, B.P. Roe, et.al., physics/0508045, NIM A555 (2005) 370

Systematic Uncertainties

- 5% Parton Density Function (PDF) uncertainty
- 5% QCD factorization scaling uncertainties used in NLO calculations
- 5% luminosity uncertainty
- 3% lepton identification acceptance uncertainty
- 6% energy scale and resolution uncertainty (3% on lepton energy, 10% on hadronic energy)
- 8% BDT training uncertainty (due to major background cross-section changes)
- 15% background estimation uncertainty (assuming 100% W/Z+Jets cross-section uncertainty).



ATLAS and CMS



	A Toroidal LHC ApparatuS	Compact Muon Solenoid
MAGNET	3 air-core toroids + solenoid in inner cavity Calorimeters in field-free region	Only one Solenoid Calorimeters inside field
TRACKER	Si pixels + strips + TRT for particle identification Solenoid B = 2T $\sigma/p_T \sim 5\times10^{-4} p_T \oplus 0.01$	Si pixels + strips Solenoid B = 4T $\sigma/p_T \sim 1.5\times10^{-4} p_T \oplus 0.005$
EM CALO	Pb-liquid Argon Longitudinal segmentation $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.007$	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E} \oplus 0.005$
HADRONIC CALO	Fe-scint. + Cu-liquid Argon (10λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. ($>5.8\lambda$+catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Optimal performance also standalone $\sigma/p_T \sim 2\%$@50GeV$\div$10%@1TeV (ID+MS)	Combining with tracker $\sigma/p_T \sim 1\%$@50GeV$\div$5%@1TeV
TRIGGER	LVL1 + LVL2 (Region of Interest) + EF	LVL1 + HLT (LVL2 + LVL3)