Search for the High Mass Standard Model Higgs Boson at ATLAS

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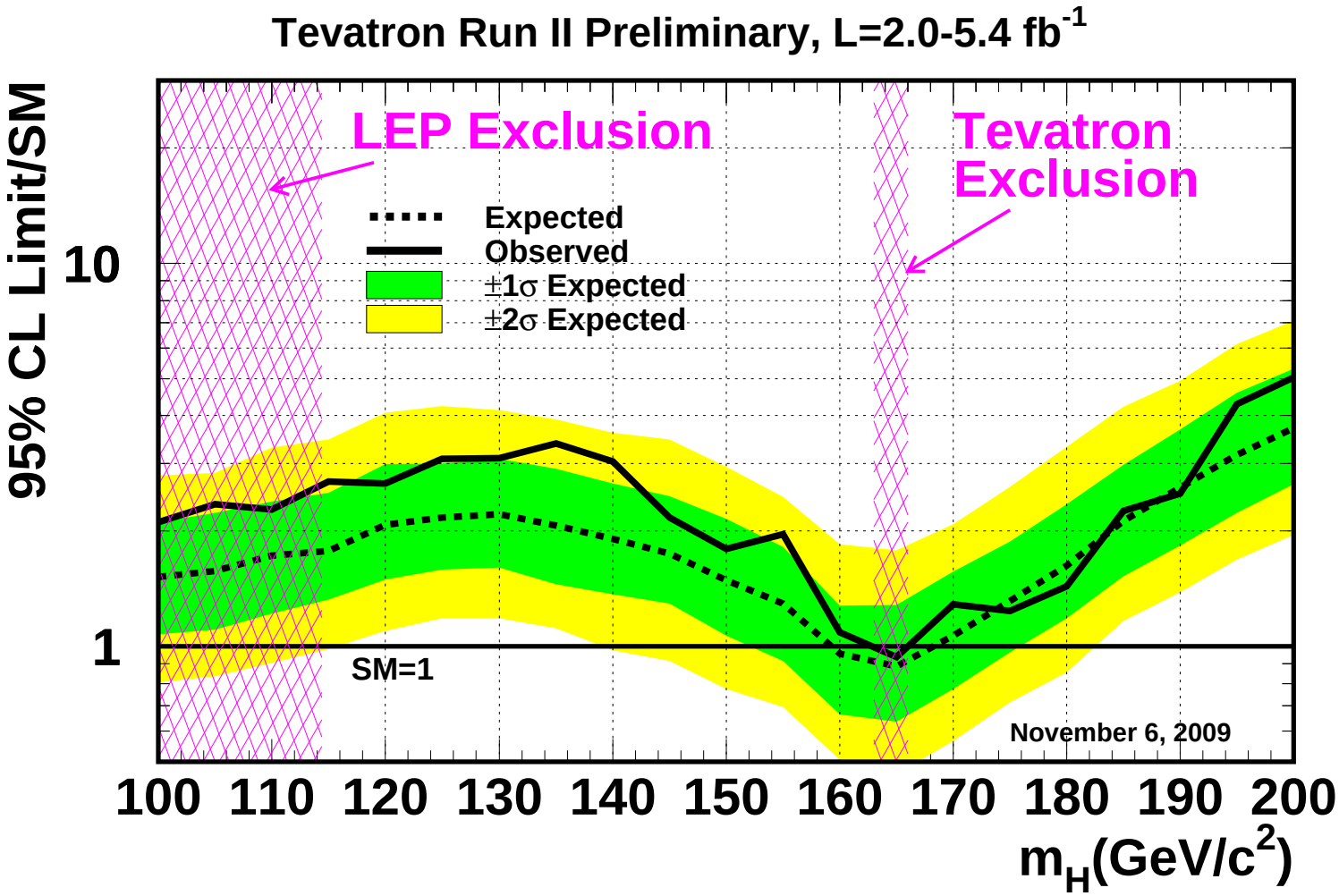
on behalf of the ATLAS Collaboration

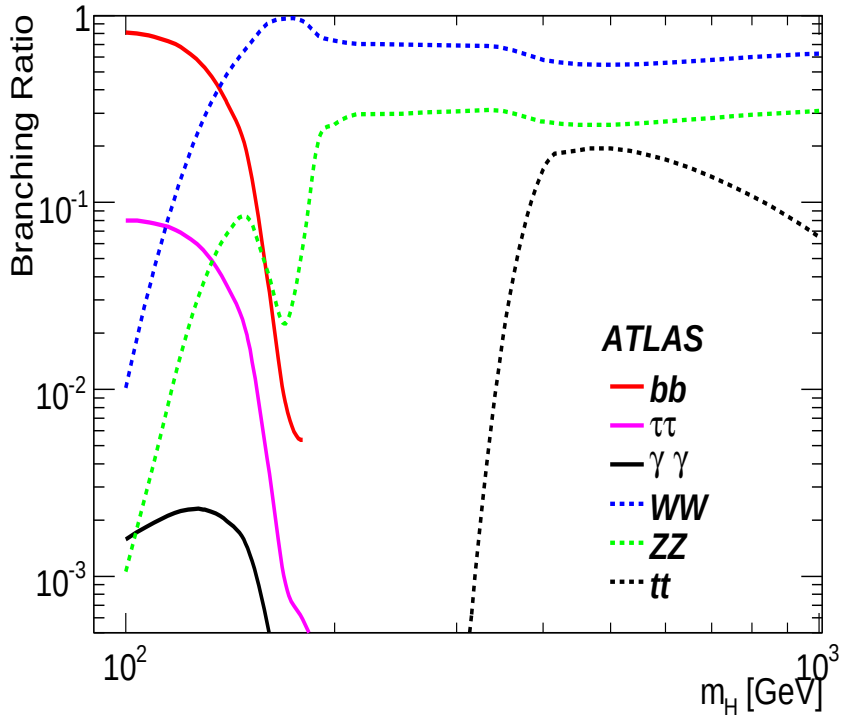
Current Tevatron Limits on the SM Higgs

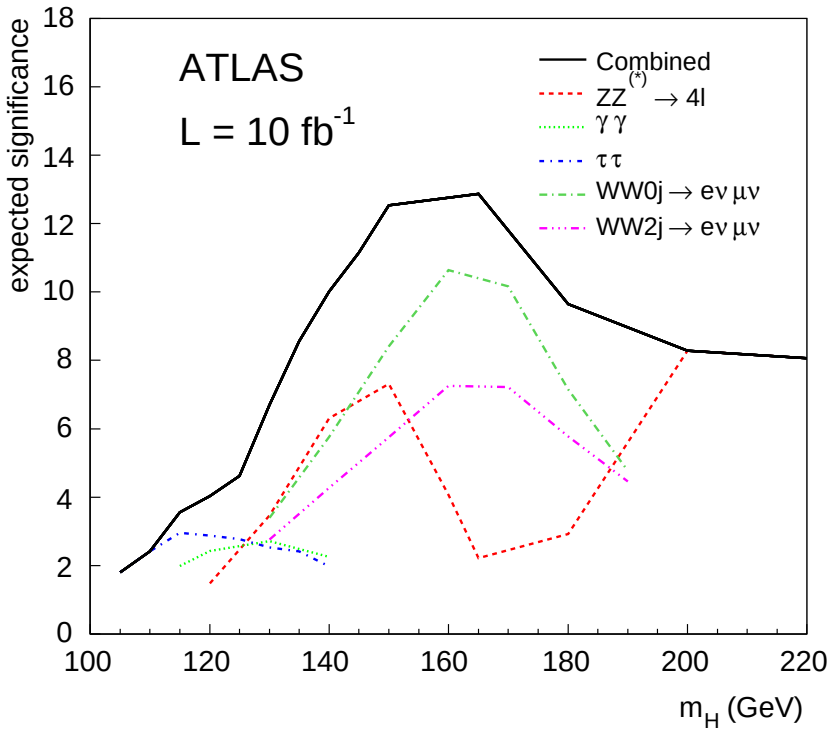


Outline of Talk

- High Mass Higgs Results from ATLAS
  - All results presented here target 10 fb^{-1} and 30 fb^{-1} at $\sqrt{s} = 14$ TeV.
  - Results are detailed in CERN-OPEN-2008-020.
- Gluon Fusion (GF) $H \rightarrow WW^{\star} \rightarrow \ell\nu\ell'\nu'$
  - Analysis Selection: Signal and Background Counts
  - Discriminating Variable Distributions: lepton separation and transverse momentum
  - Expected Sensitivity and Linearity after 10fb^{-1}
- Vector Boson Fusion (VBF) $H \rightarrow WW^{\star} \rightarrow \ell\nu\ell'\nu'$
  - Discriminating Variable Distributions: tag jets and jet b weight
  - Analysis Selection: Signal and Background Counts
  - Expected Sensitivity and Linearity after 10fb^{-1}
- GF and VBF $H \rightarrow ZZ^{\star} \rightarrow \ell^{+}\ell^{-}\ell'^{+}\ell'^{-}$
  - Discriminating Variable Distributions: lepton isolation and IP significance
  - 4ℓ Mass Distributions and Resolution
  - Analysis Selection: Signal and Background Counts
  - Expected Exclusion and Significance after 30fb^{-1}

What is a High Mass SM Higgs?

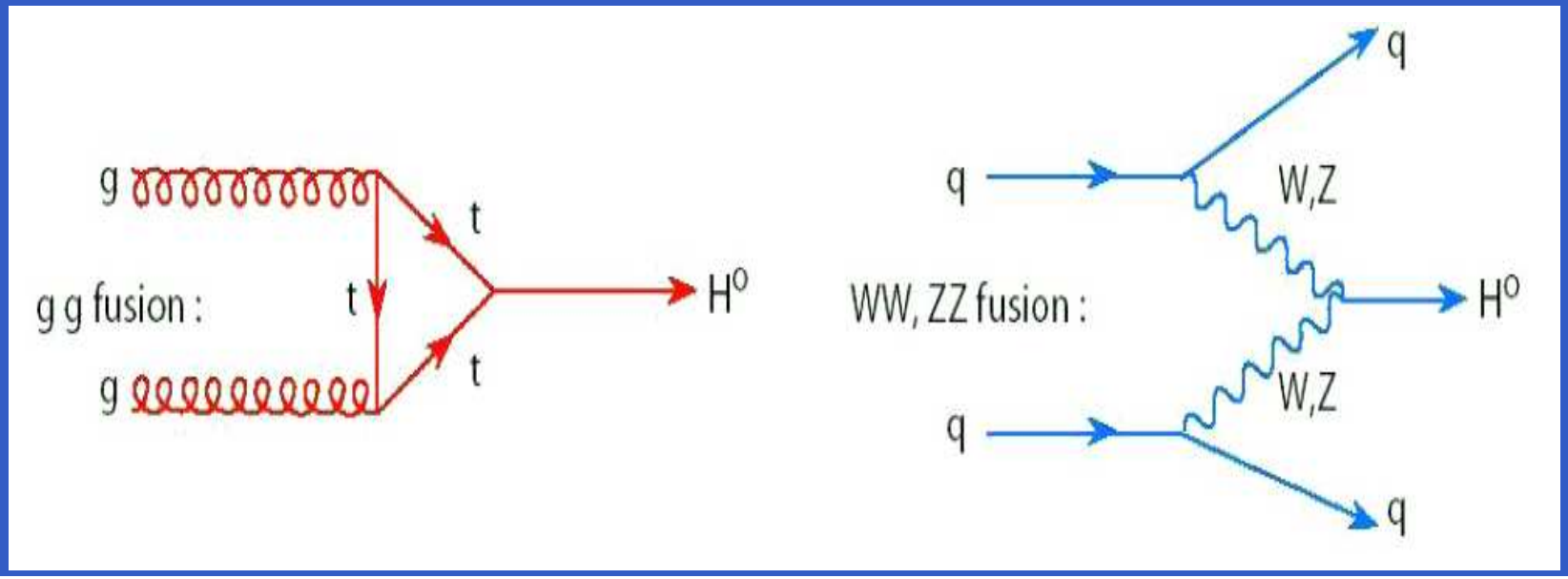


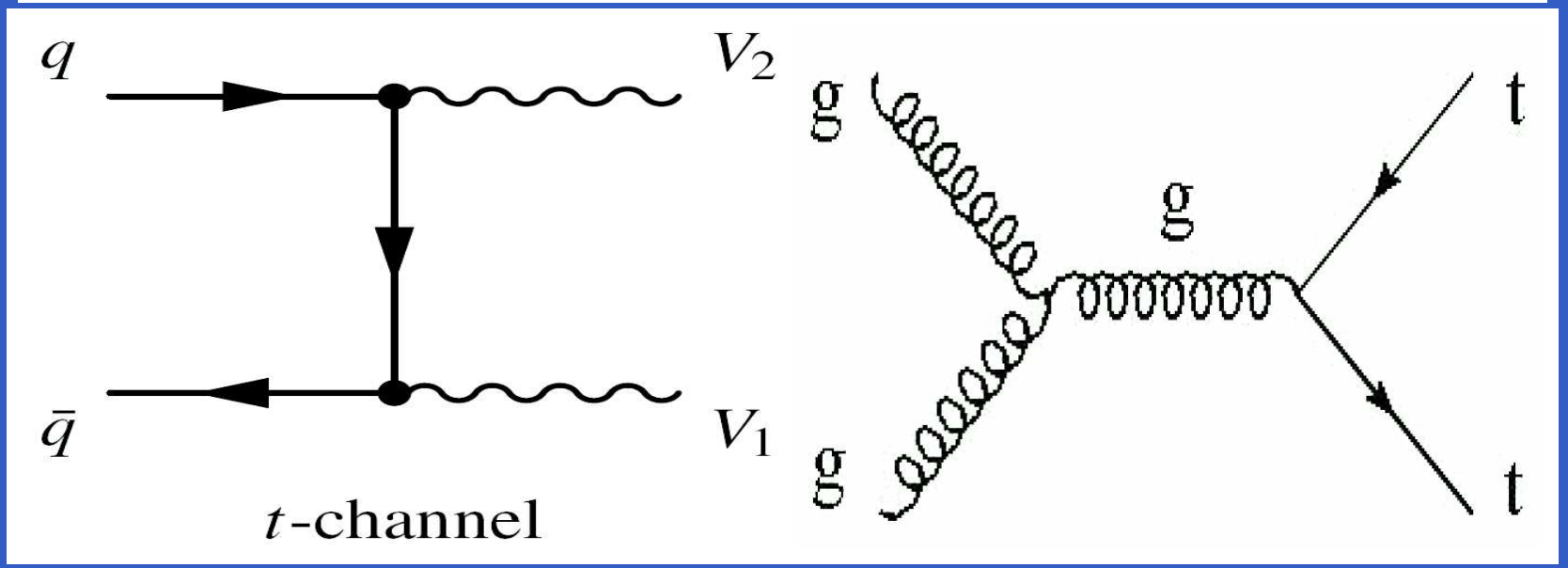


An operational definition of a high mass SM Higgs boson is a SM Higgs with mass at or above where $H \to ZZ^\star/WW^\star$ sensitivity begins to dominate other channels, around 130 GeV.

VBF+GF $H \to WW^{\star}$: Signal and Background Topologies

Left: GF signal, $WW^{\star}$. Right: VBF signal: $WW^{\star}$ plus two (*tag*) jets. Courtesy I.C.





Left: GF background, diboson WW, t-channel. Right: VBF background: WW plus two b jets

VBF+GF $H \rightarrow WW^{\star}$: Reco. and Statistical Formalism

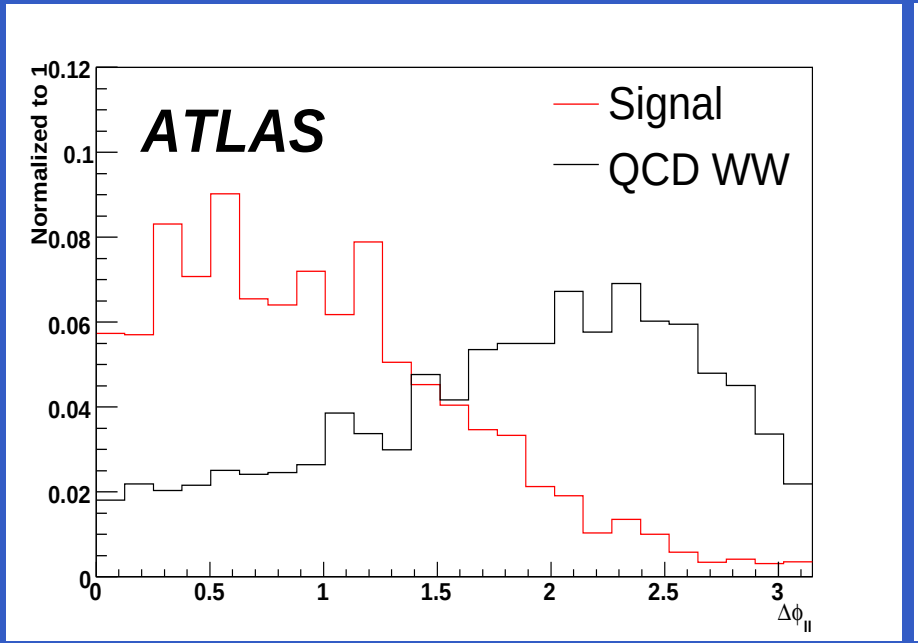
- Object Reconstruction
  - Trigger. e22i or mu20 or 2e15i or e60. For both GF and VBF, 95% efficiency.
  - Leptons. $E_T > 15$ GeV, $|\eta| < 2.5$, IP significance <10, track and calorimeter isolation.
  - Jets. Cone algorithm with $\Delta R = 0.4$ with topological clusters and $E_T > 20$ GeV.
  - Missing E_T. Cell based reconstruction.
- Statistical Formalism
  - 2D maximum likelihood fits to distributions after full signal selection.
  - Likelihood ratio $\lambda = L_{S+B}/L_B$, numerator and denominator from separate fits to data. Higgs mass parameter floats free in the fits.
  - Sensitivity is determined from observed value of λ in data and distributions of the LR λ generated by toy MC experiments.
- Fitted Distributions
  - GF: transverse mass and momentum of the $WW^{\star}$ system. Background is mainly WW.
  - VBF: transverse momentum of the $WW^{\star}$ system and neural network output (with tag jet inputs). Background is mainly $t\bar{t}$.

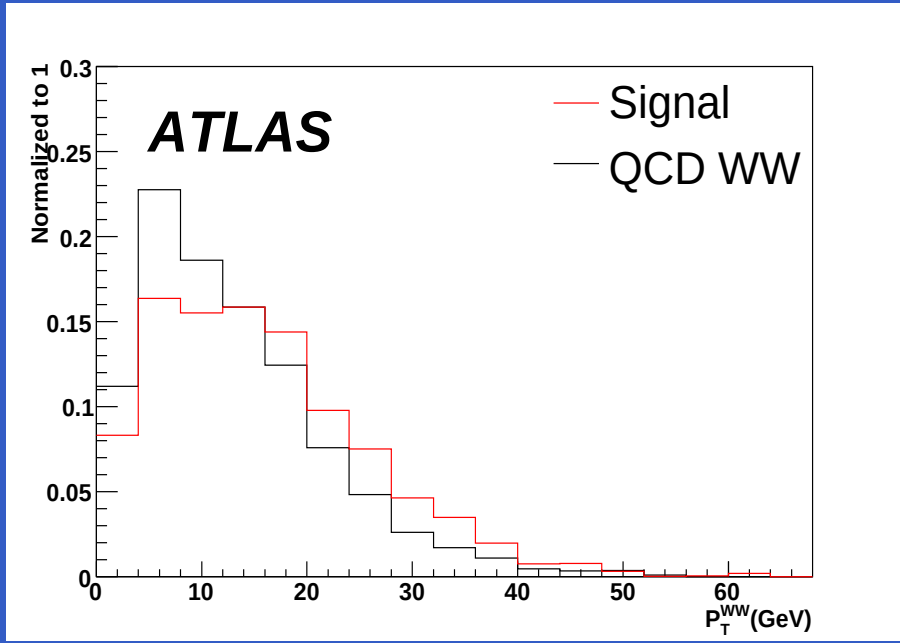
GF $H \to WW^{\star}$: Signal Selection

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	-	-	-

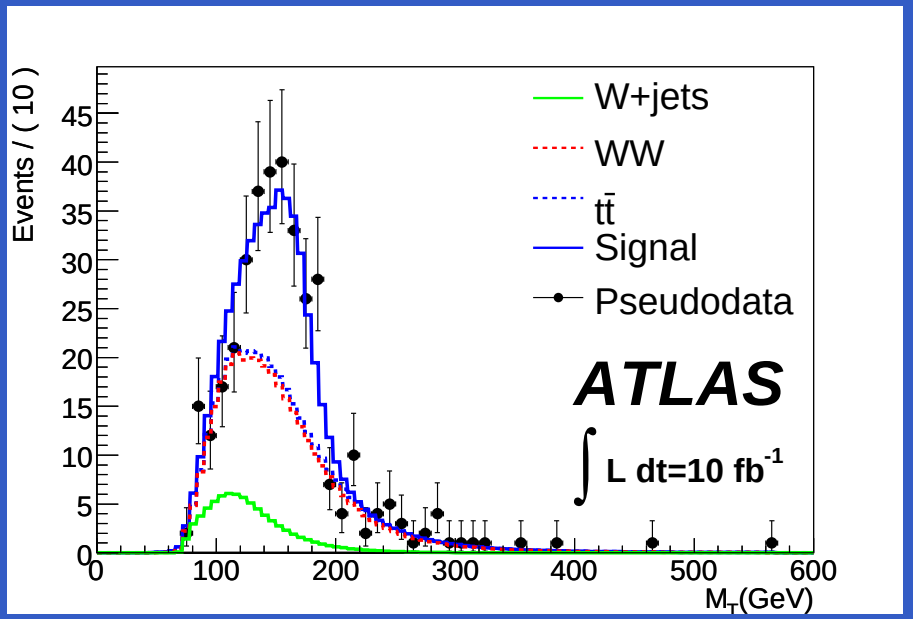
Cut flows (in fb)for $m_H = 170$ GeV in the H+0j, $H \to WW^{\star} \to e\nu\mu\nu$ channel. A '-' indicates the corresponding contribution is ignored in the fit. The WW background contains the two processes $q\bar{q} \to WW$ and $gg \to WW$.

GF $H \rightarrow WW^{\star}$: Discriminating Variables

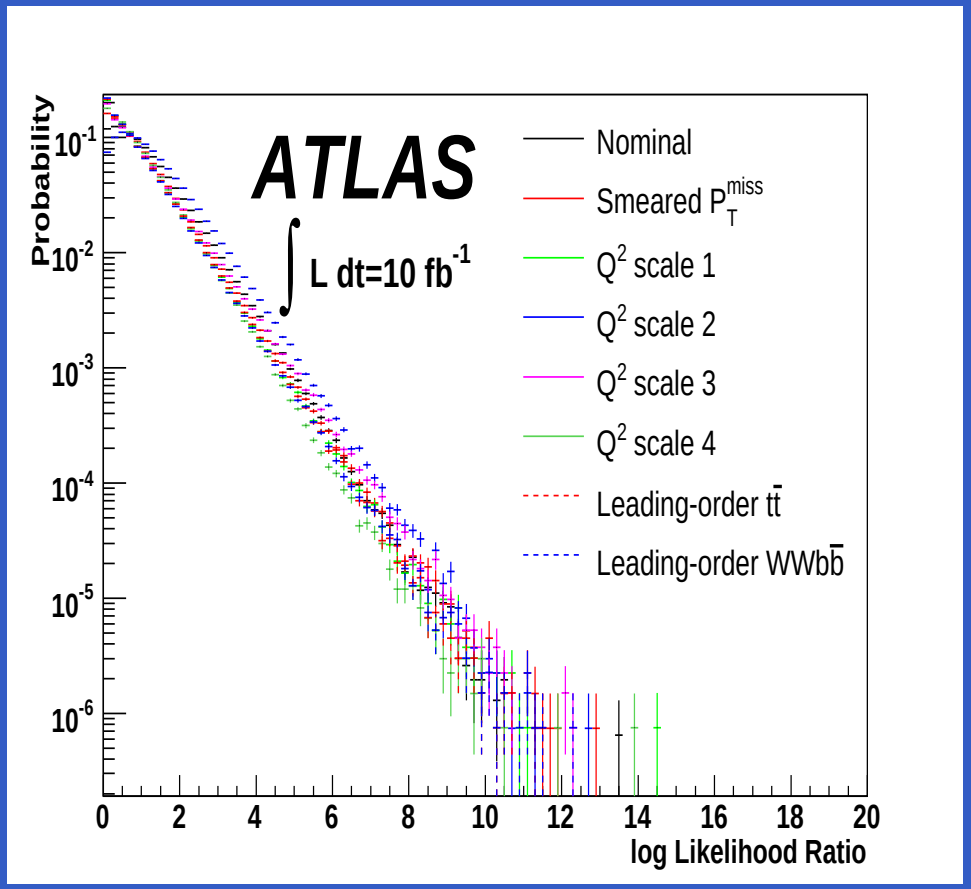


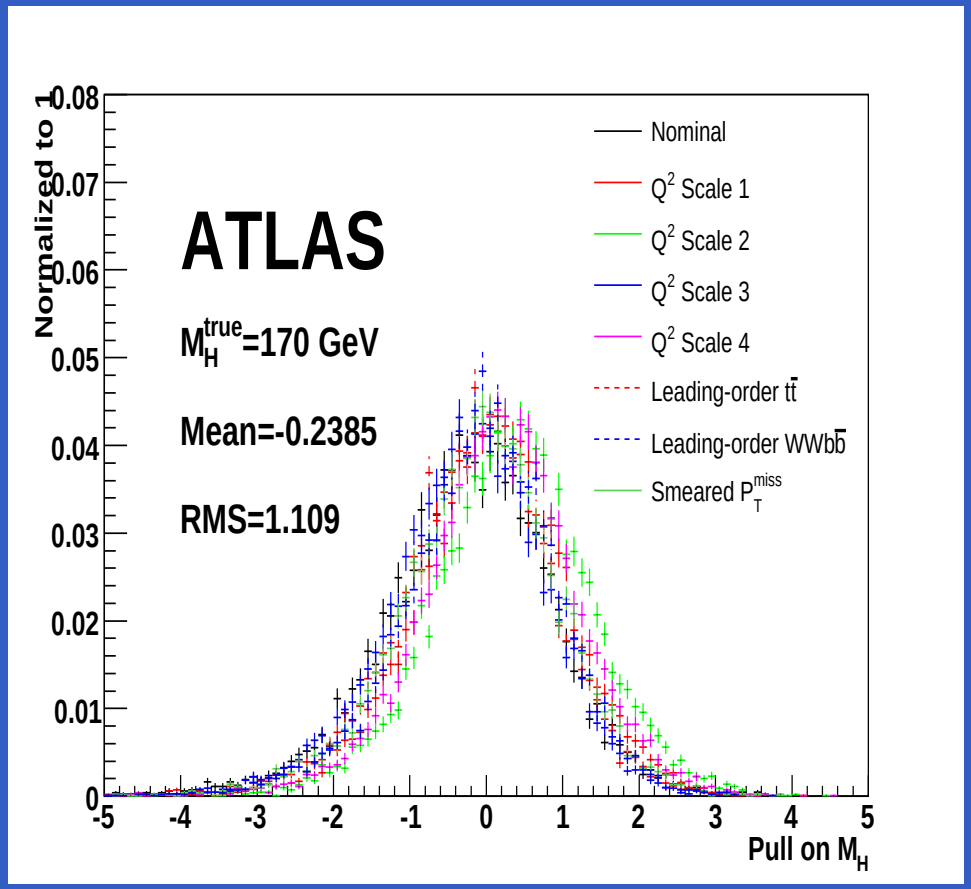


- $\Delta\phi_{\ell\ell'}$, the opening angle between the leptons from W decay after preselection [H is scalar](top left)
- p_T^{WW}, the transverse momentum of the WW system after preselection (top right)
- m_T^{WW}, the transverse mass of the WW system for events satisfying $\Delta\phi_{\ell\ell'} < 1.575$ and $p_T^{WW} > 20$ GeV (right)



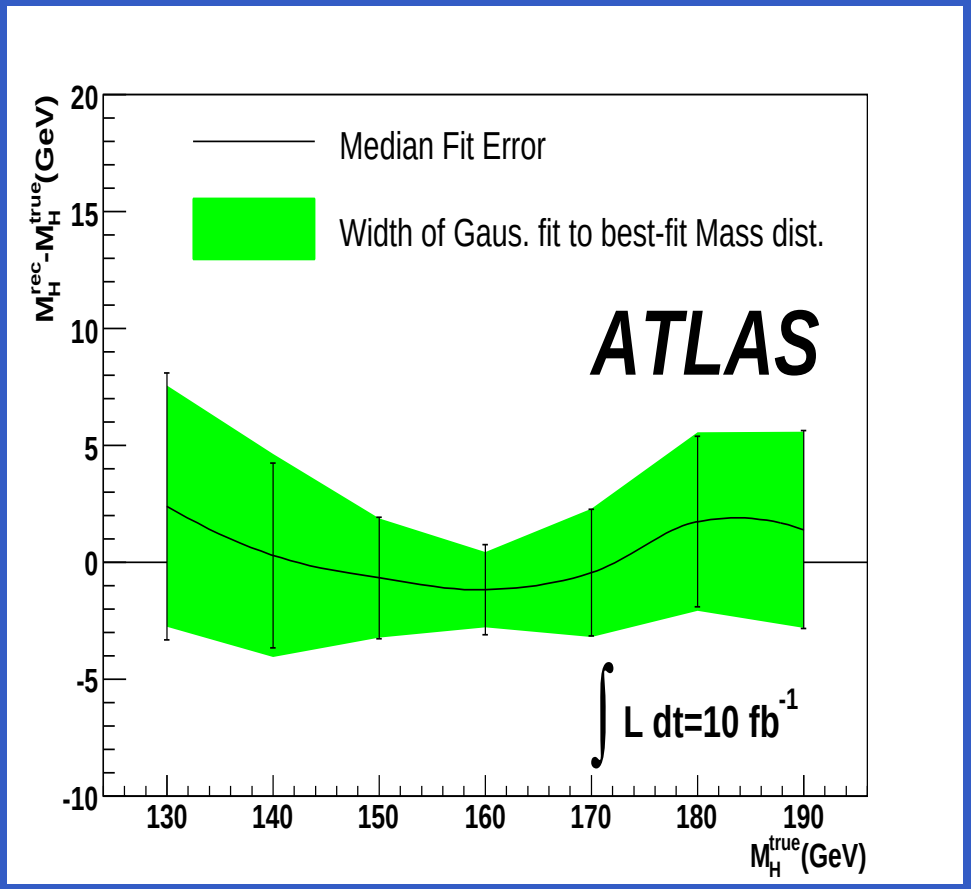
GF $H \to WW^{\star}$: LR Distributions and Mass Pull

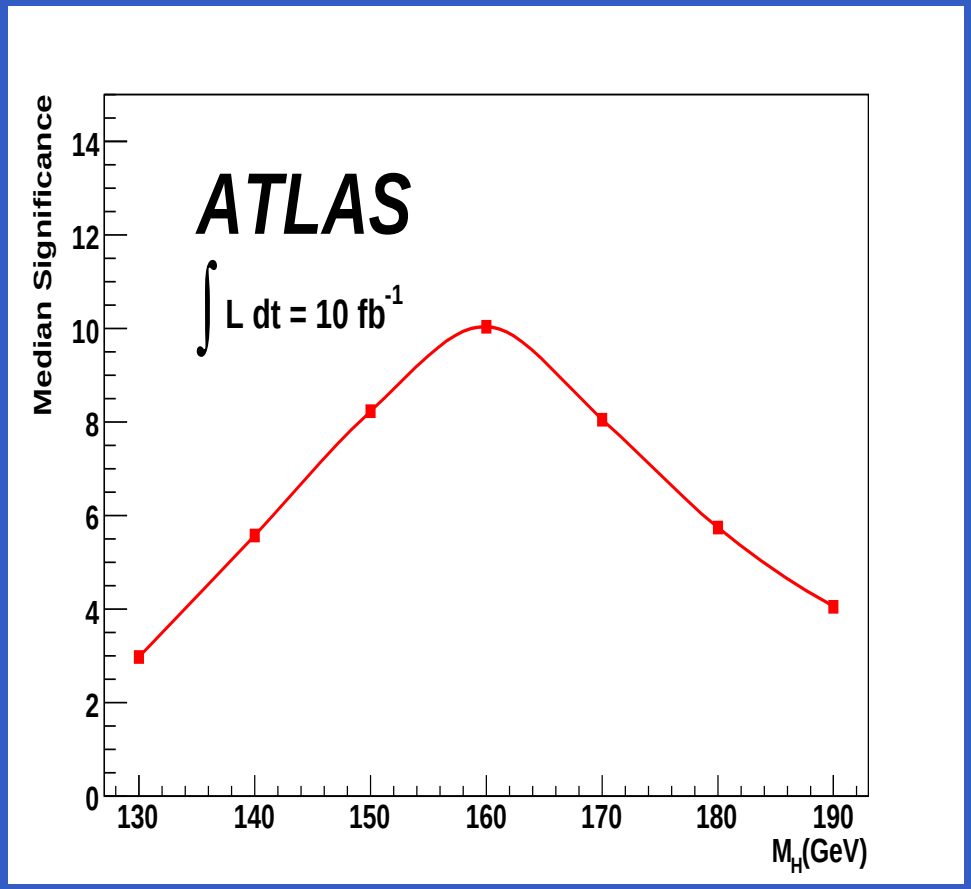




At left, the log likelihood distributions for background-only toy MC outcomes corresponding to 10 fb^{-1}. The variously colored lines model sources of systematic uncertainty from factorization and normalization scales and background model. At right the pull distribution for $m_H = 170$ GeV.

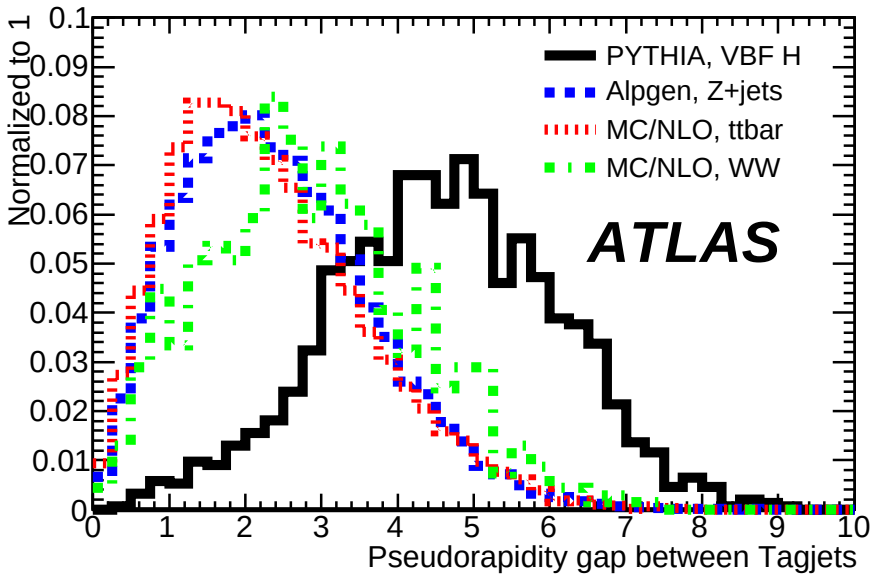
GF $H \to WW^{\star}$: Linearity and Sensitivity ($e\mu$ only)

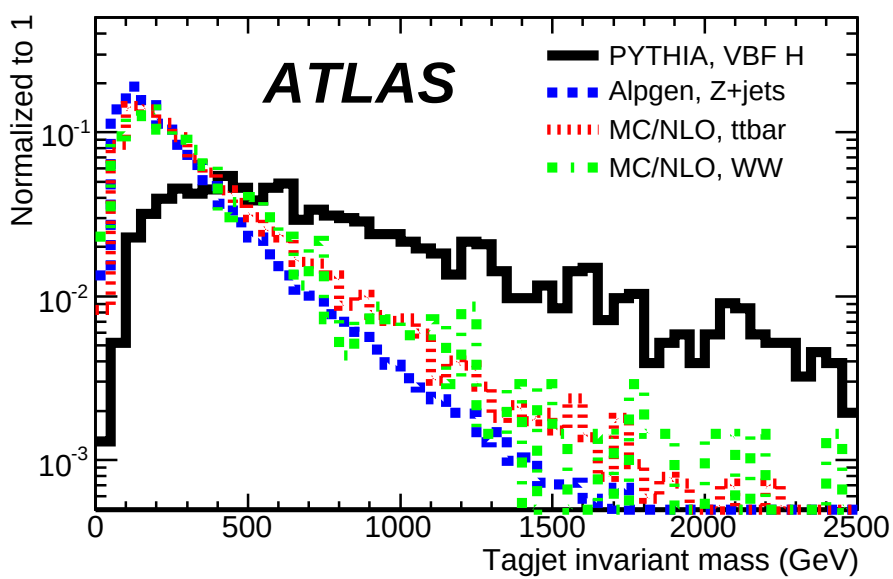


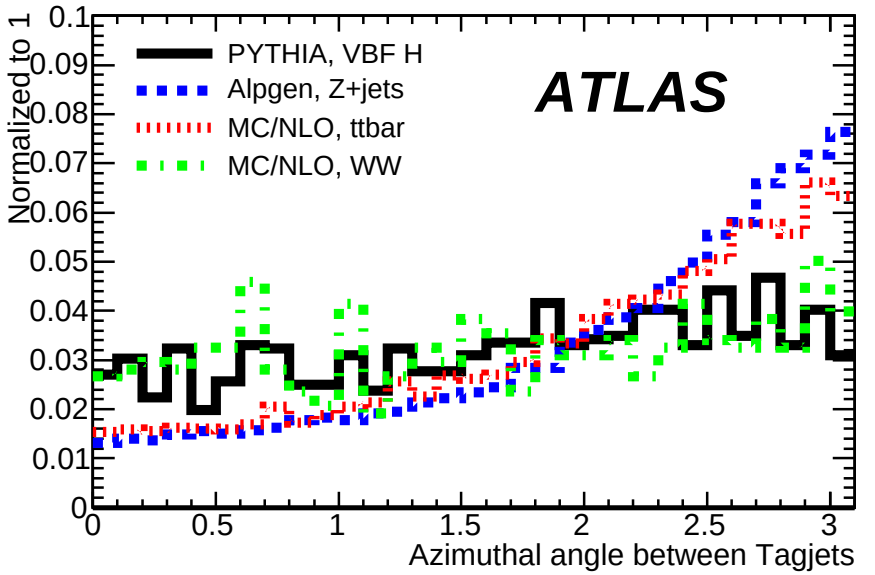


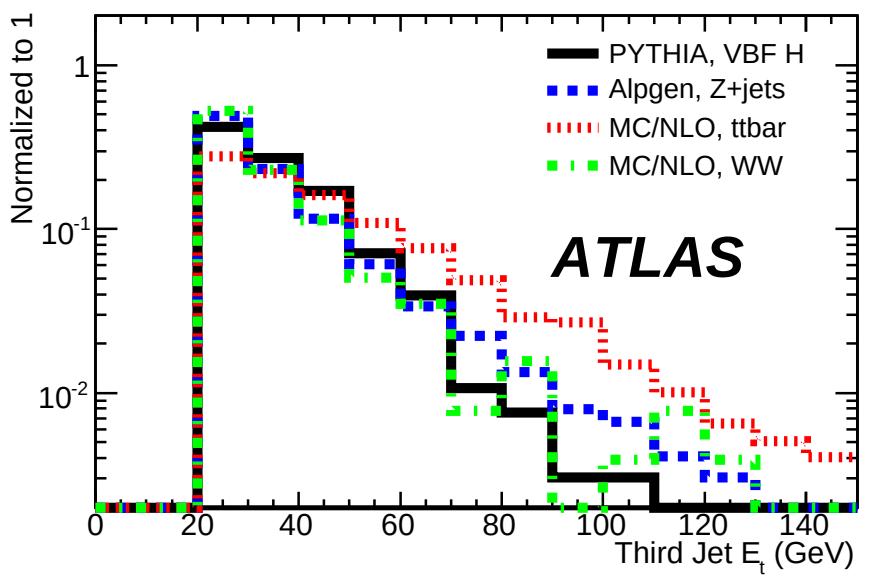
Linearity and sensitivity for gluon fusion $H \to WW^{\star}$. At left, measured v. true Higgs mass demonstrates no bias in the mass measurement. At right, sensitivity v. Higgs mass at 10fb^{-1}.

VBF $H \rightarrow WW^{\star}$: Discriminating Variables (tag jets)

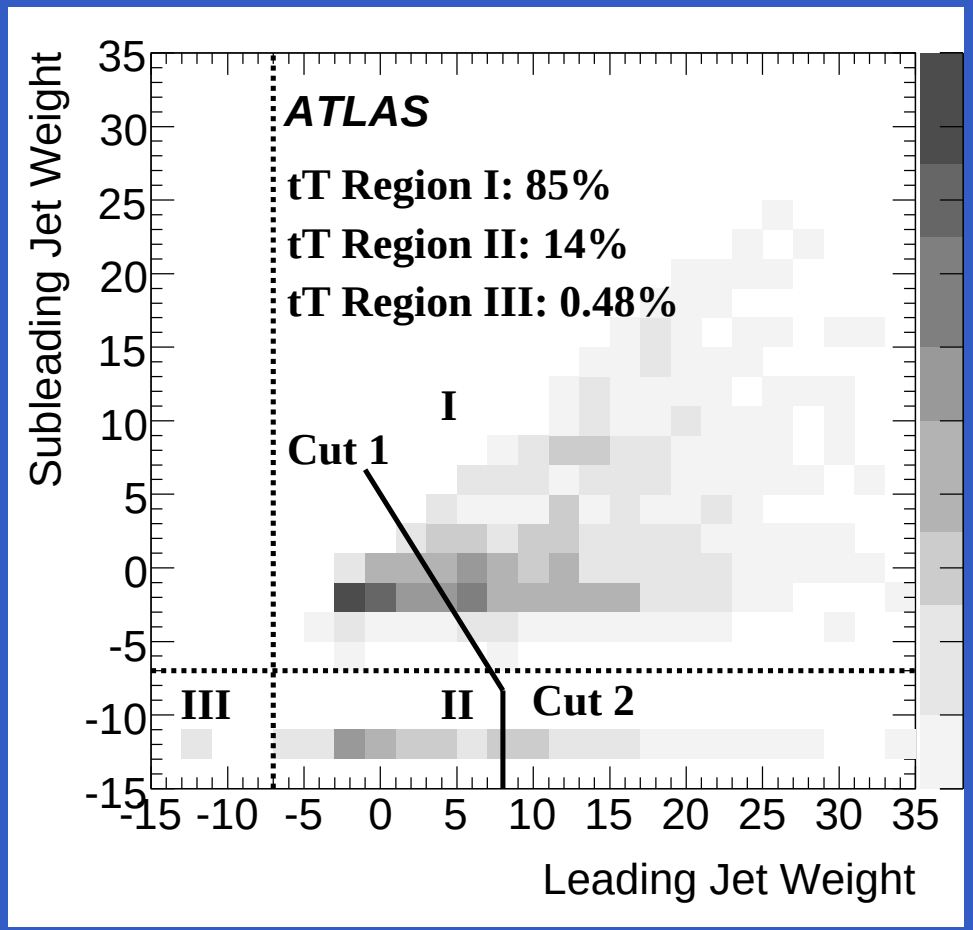


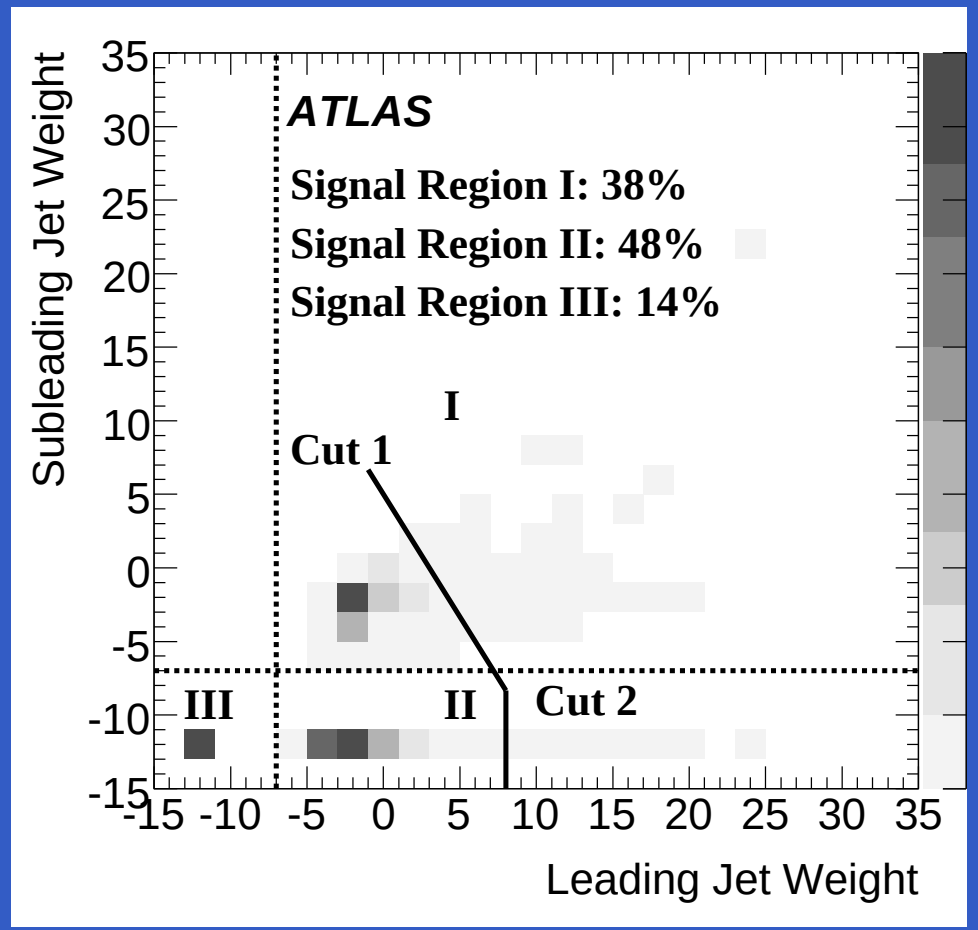






VBF $H \rightarrow WW^{\star}$: Discriminating Variables (b tag)





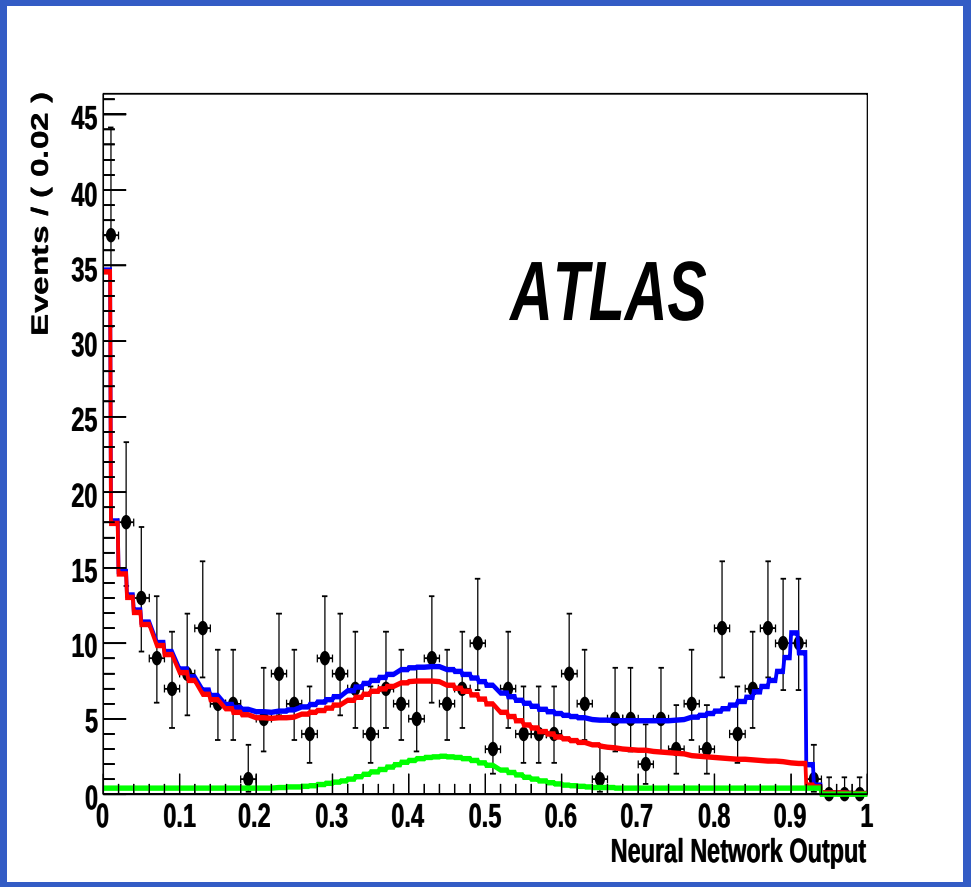
Leading versus sub-leading jet weights in the events for $t\bar{t}$ background (left) and signal (right). Plots are divided in three regions: I where there is a non-default b-tagging weight for more than one jet, II where there is b-tagging information for only one jet in the event and III where there are no jets with b-tagging information in the event.

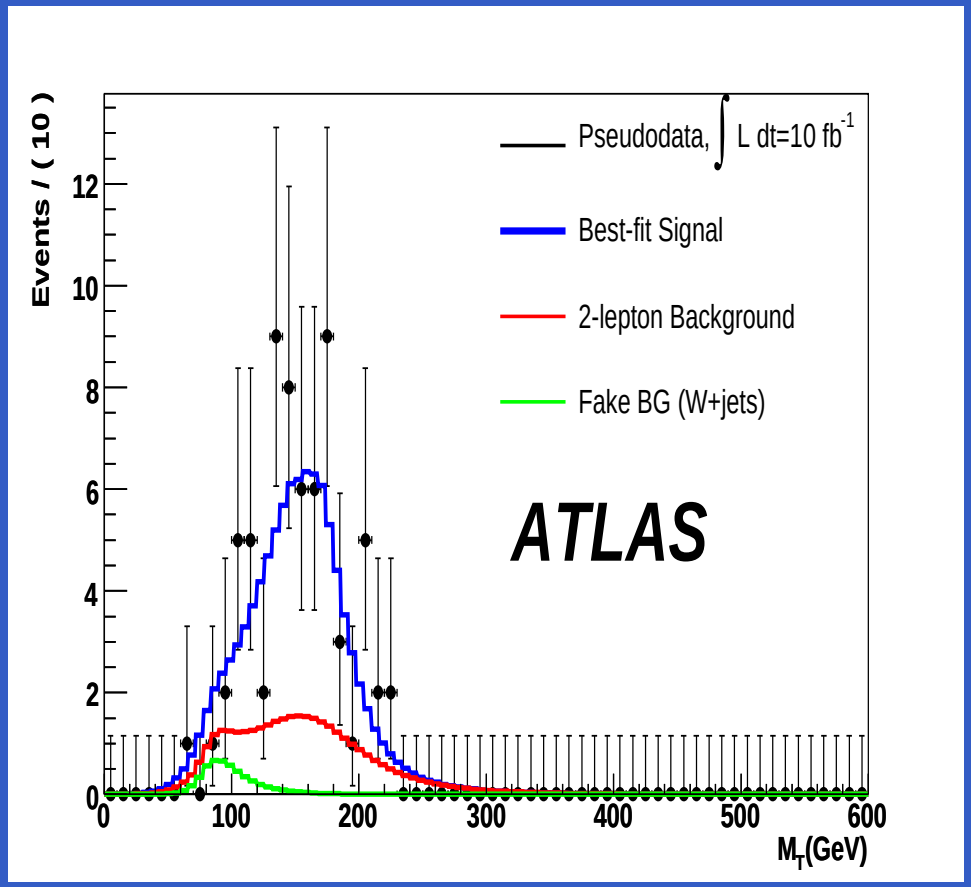
VBF $H \to WW^\star$: Signal Selection

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

Cut flow (in fb) for $m_H = 170$ GeV in the $H + 2j$, $H \to WW^\star \to \mu\nu e\nu$ channel. Numbers in parentheses are affected by generator level cuts. The signal region is defined by $\delta\phi_{\ell\ell} < 1.5$ and $\delta\eta_{\ell\ell} < 1.4$, the control is everywhere else.

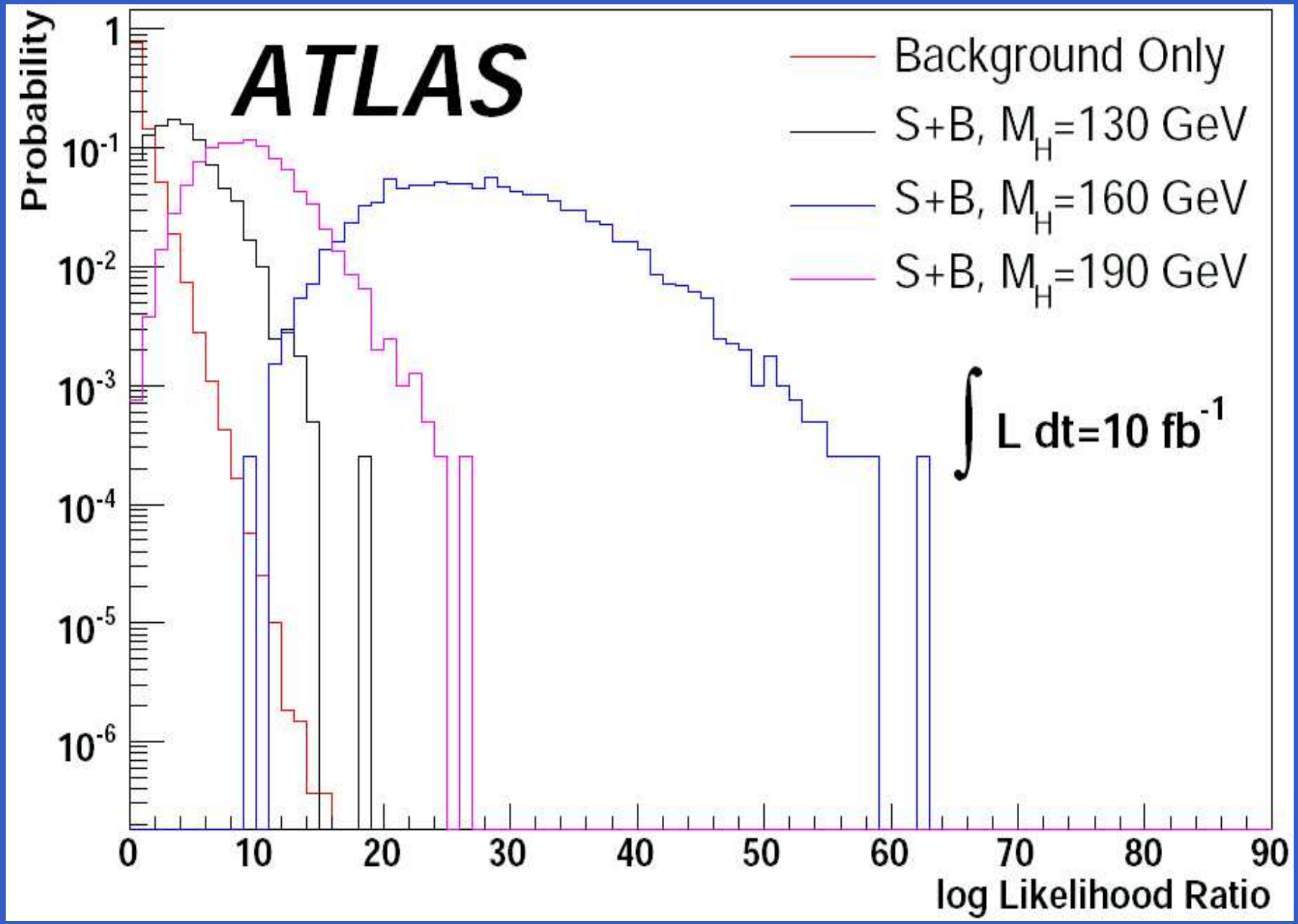
VBF $H \rightarrow WW^{\star}$: Discriminating Variables (NN, m_T)



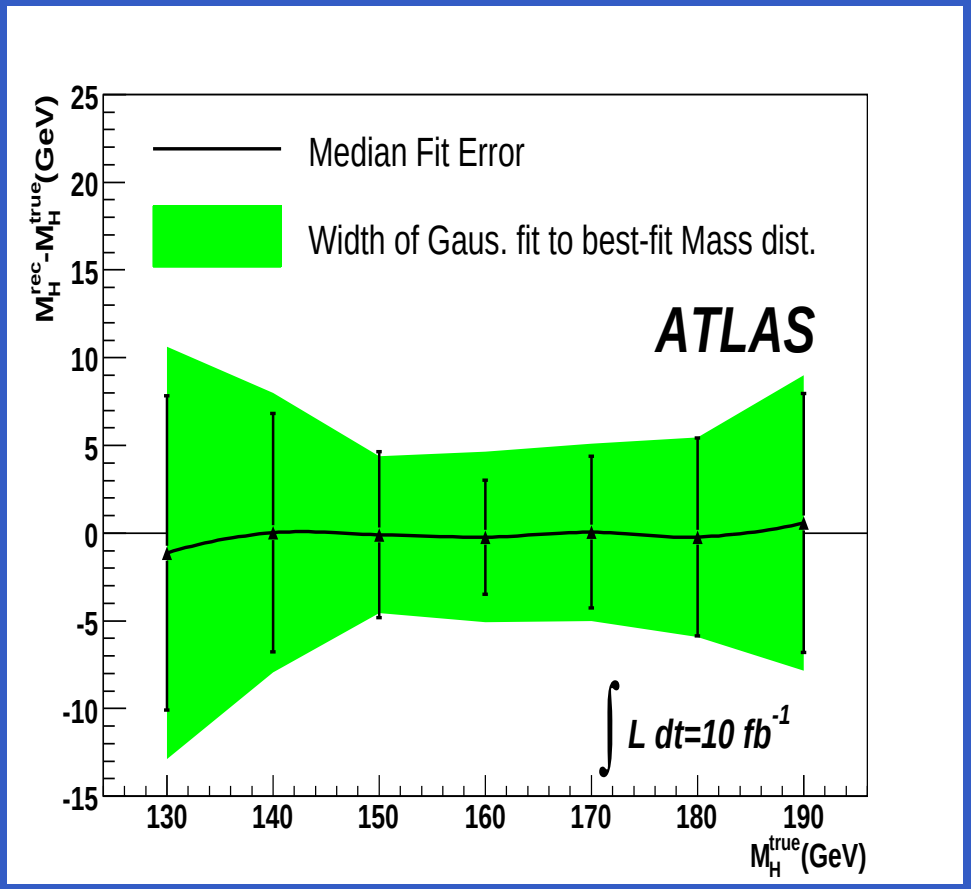


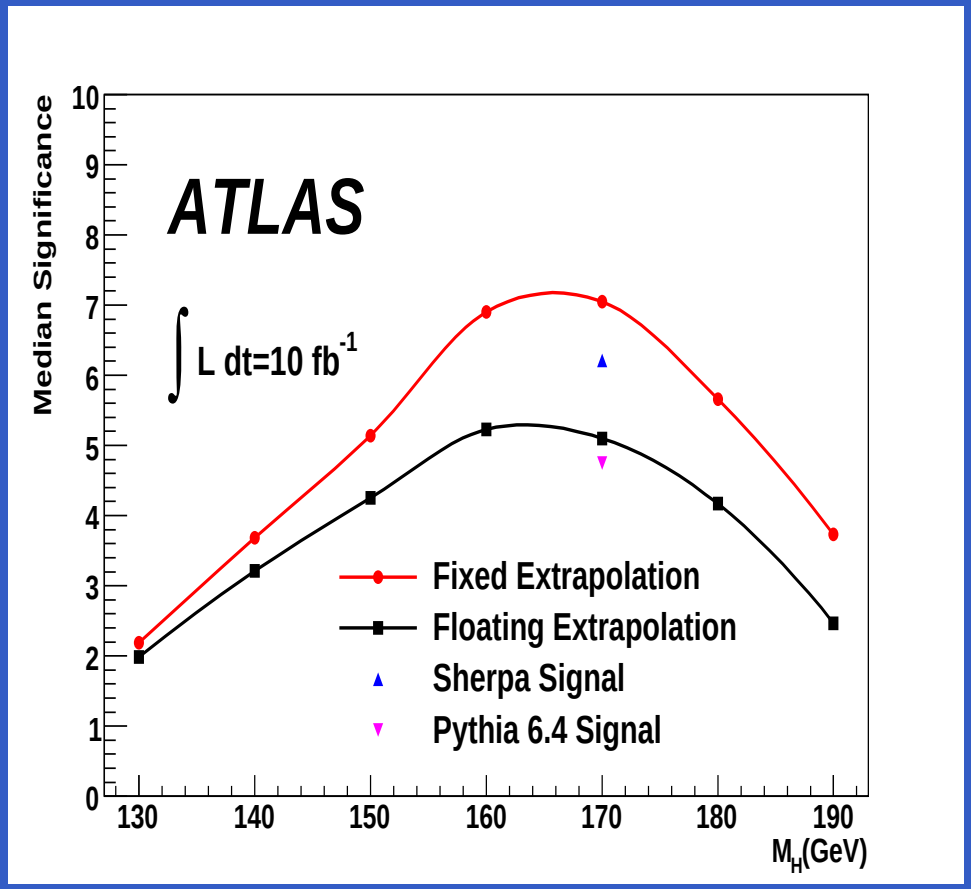
At left, the NN output distribution in the signal box for events with $50 < m_T < 180$ GeV. NN inputs are tag jet variables: $\Delta\eta$, m_{jj}, p_T^{j3} and $\eta^{\star} = \eta_3 - (\eta_1 + \eta_2)/2$. At right, the transverse mass distribution for events in the signal box with N output larger than 0.8 (10fb^{-1}, $m_H = 170$ GeV).

VBF $H \rightarrow WW^{\star}$: Likelihood Ratio Distributions



VBF $H \rightarrow WW^{\star}$: Linearity and Sensitivity ($e\mu$ only)

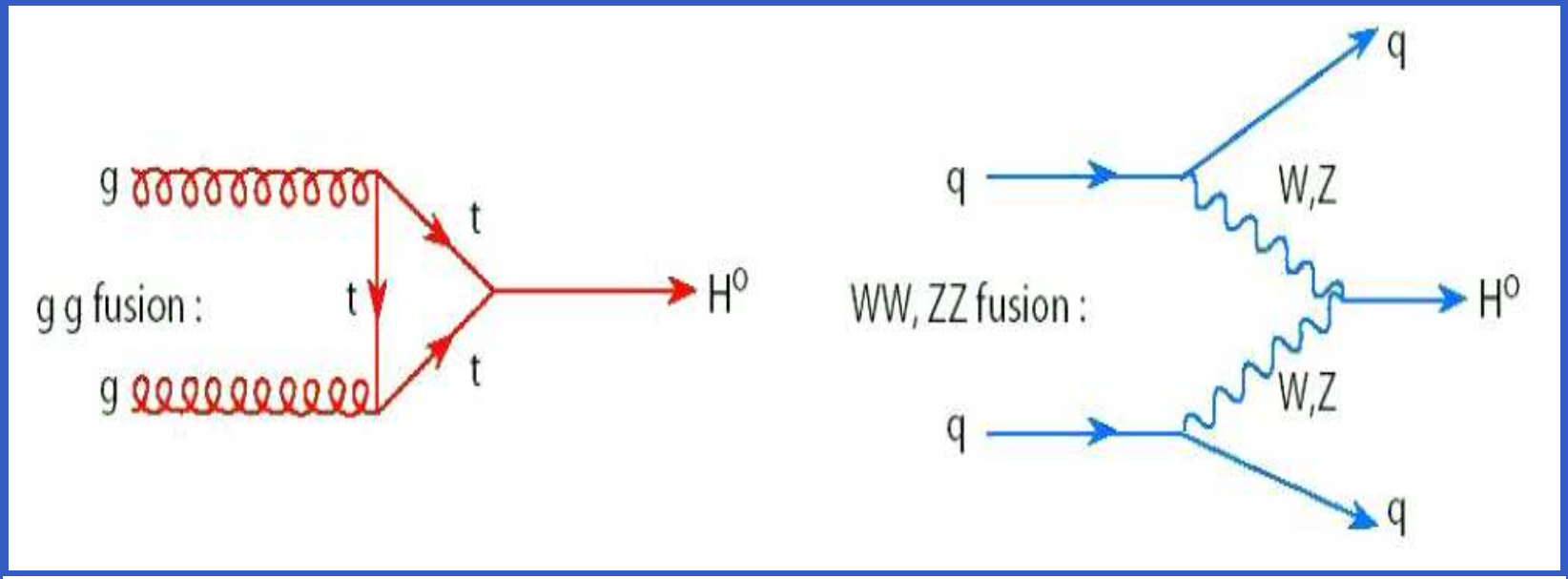


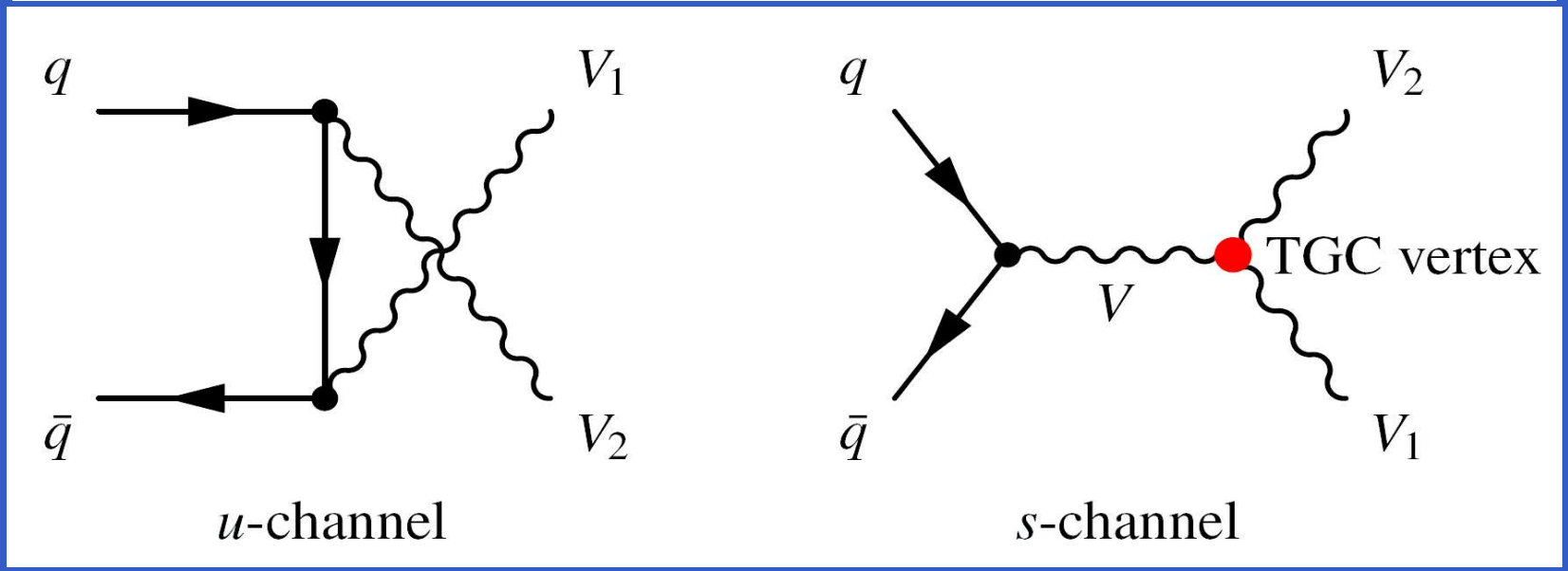


Linearity and sensitivity for VBF $H \rightarrow WW^{\star}$. At left, linearity v. true Higgs mass. At right, sensitivity v. Higgs mass at 10fb^{-1}.

VBF+GF $H \to ZZ^{\star}$: Signal and Background Topologies

Left: GF signal, $ZZ^{\star}$. Right: VBF signal: $ZZ^{\star}$ plus two (*tag*) jets. Courtesy I.C.



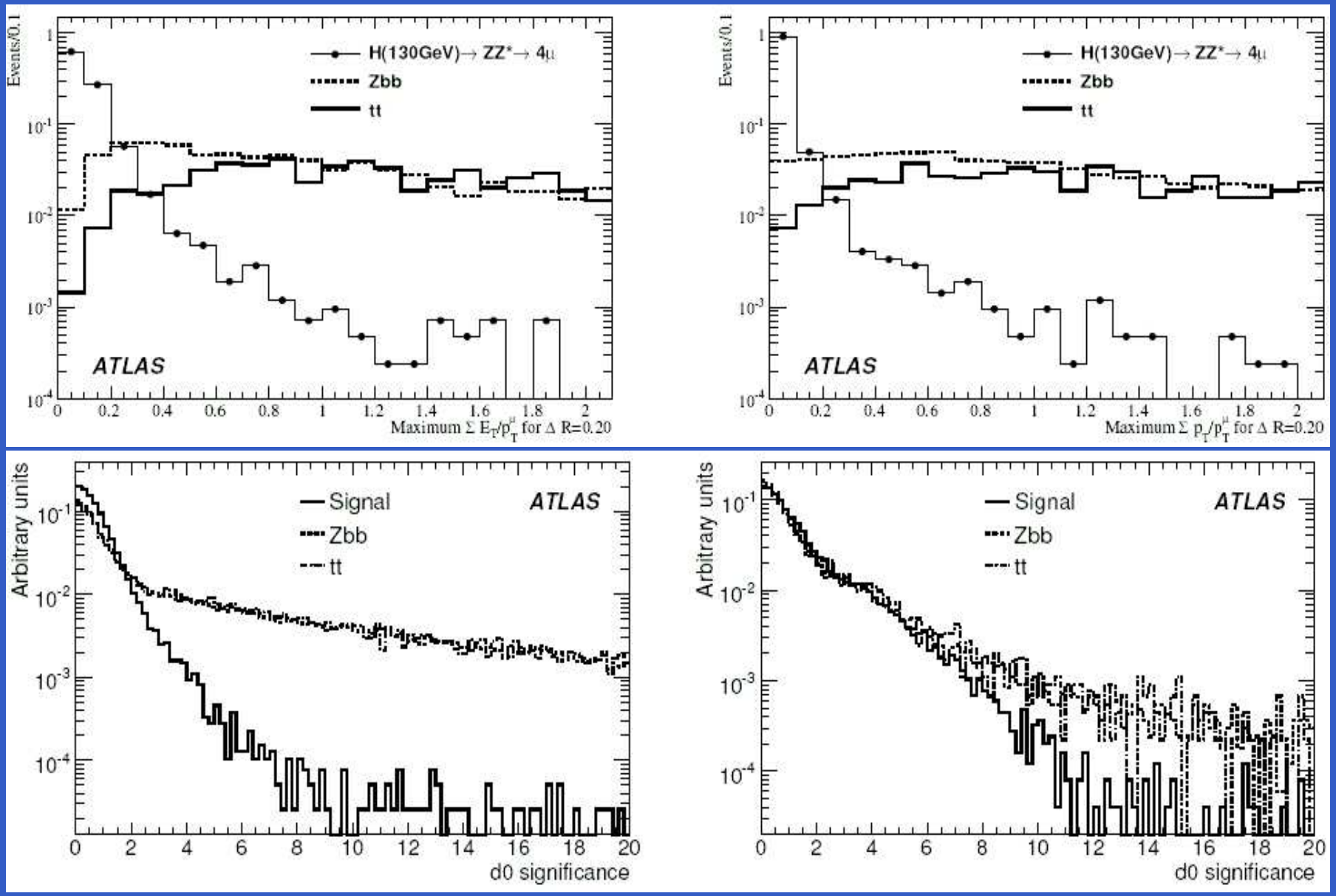


Diboson ZZ, u- and s-channels.

VBF+GF $H \rightarrow ZZ^{\star} -$: Reco. and Statistical Formalism

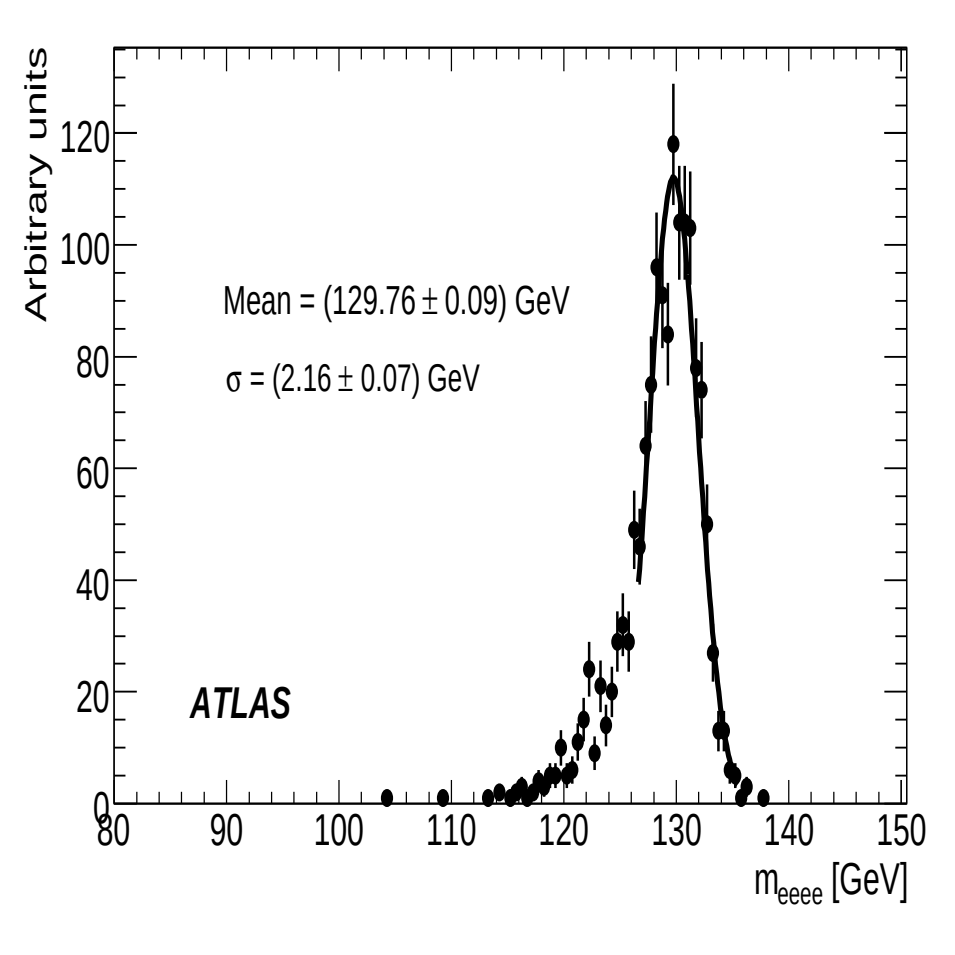
- Object Reconstruction
  - Trigger. e22i or mu20. Efficiency is 95% before offline selection, 99% after offline selection.
  - Electrons. IP significance <6, track isolation $\sum_{\Delta R=0.2} p_T/p_T < 0.15$ and calorimeter isolation, $p_t > 7$ GeV and $|\eta| < 2.5$.
  - Muons. IP significance <3.5, track isolation $\sum_{\Delta R=0.2} p_T/p_T < 0.15$ and calorimeter isolation $\sum_{\Delta R=0.2} p_T/p_T < 0.23$, $p_t > 7$ GeV and $|\eta| < 2.5$.
- Statistical Formalism
  - Fit the likelihood ratio $\lambda = L(\mu, \hat{\hat{\mathbf{p}}})/L(\hat{\mu}, \hat{\mathbf{p}})$, where $\mu = 0(1)$ corresponds to no signal (SM expected signal).
  - Approximate the signal significance from the test statistic $\sqrt{-2 \ln \lambda(\mu)}$.
  - Obtain the exclusion with the background only hypothesis with $\sqrt{-2 \ln \lambda(\mu)} = 1.64$
- Fitted Distribution
  - 1D maximum likelihood fit, with parameters $\mathbf{p}$ to the 4ℓ mass distribution.
  - Signal fits with Gaussian, WW is fit with double Fermi function.

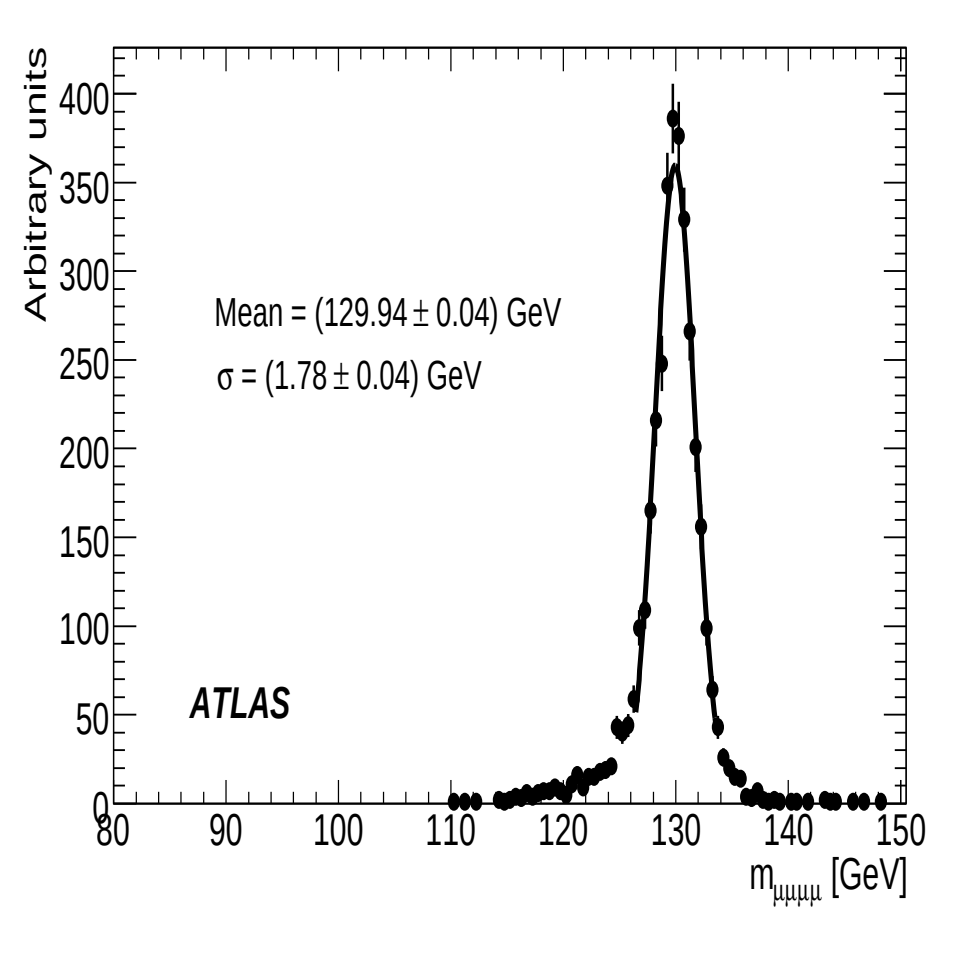
VBF+GF $H \to ZZ^\star \to 4\ell$: Discriminating Variables



At top, calorimeter isolation (left) for 4μ and track isolation (right) for 4μ. At bottom, IP significance for 4μ (left) and $4e$ (right).

VBF+GF $H \rightarrow ZZ^{\star} \rightarrow 4\ell$: 4ℓ Mass Distribution





$4e$ mass distribution (left) and 4μ mass distribution (right)

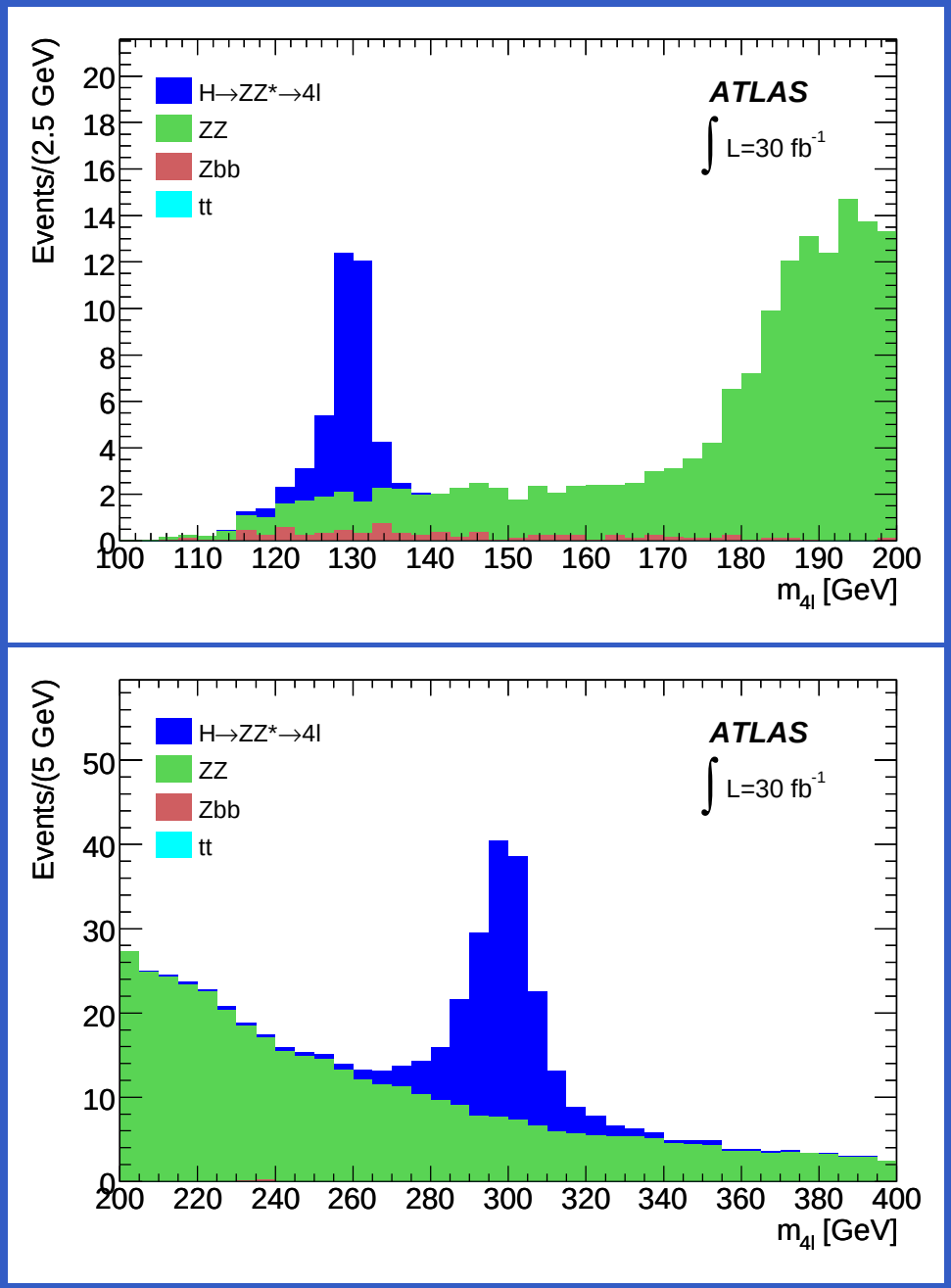
VBF+GF $H \to ZZ^\star \to 4\ell$: Signal Selection

Selection cut	Selection step	Signal		
		4e	4μ	$2e2\mu$
Trigger selection	1	94.7	95.3	95.7
Lepton preselection	2	57.0	73.8	66.8
Lepton quality and p_T	3	24.7	60.5	39.7
Z's mass cuts	4	17.1	42.9	27.6
Calo Isolation	5	17.1	39.5	25.4
Tracker Isolation	6	16.5	38.1	24.7
IP cut	7	15.1	36.5	23.2
H Mass cut	8	12.5±0.3	31.4±0.5	19.2±0.4

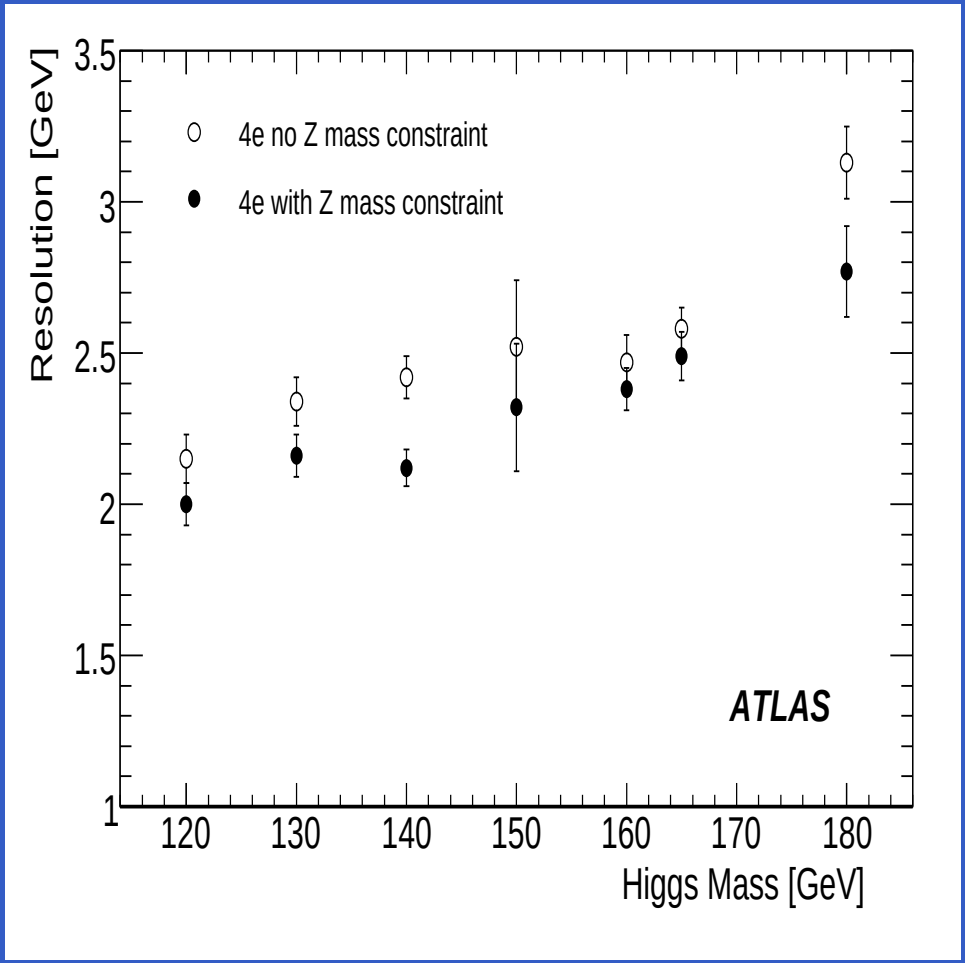
Selection cut		ZZ			Zbb		
		4e	4μ	$2e2\mu$	4e	4μ	$2e2\mu$
Trigger	1	96.6	96.6	96.6	91.4	91.4	91.4
Preselection	2	13.8	17.6	31.4	2.6	9.4	12.0
Lepton quality and p_T	3	7.3	16.0	21.9	$1.1\cdot10^{-1}$	2.1	1.7
Z mass cuts	4	6.9	14.8	20.2	$4.7\cdot10^{-2}$	1.1	$8.4\cdot10^{-1}$
Calo Isolation	5	6.9	13.9	19.5	$4.7\cdot10^{-2}$	$8.5\cdot10^{-2}$	$1.2\cdot10^{-1}$
Track Isolation	6	6.8	13.6	19.2	$1.3\cdot10^{-2}$	$3.3\cdot10^{-2}$	$4.4\cdot10^{-2}$
IP cut	7	6.2	13.0	17.8	$5.6\cdot10^{-3}$	$1.1\cdot10^{-2}$	$1.8\cdot10^{-2}$
H Mass window	8	$5.2\cdot10^{-2}$	$11.3\cdot10^{-2}$	$12.0\cdot10^{-2}$	$1.6\cdot10^{-3}$	$1.2\cdot10^{-3}$	$3.0\cdot10^{-3}$

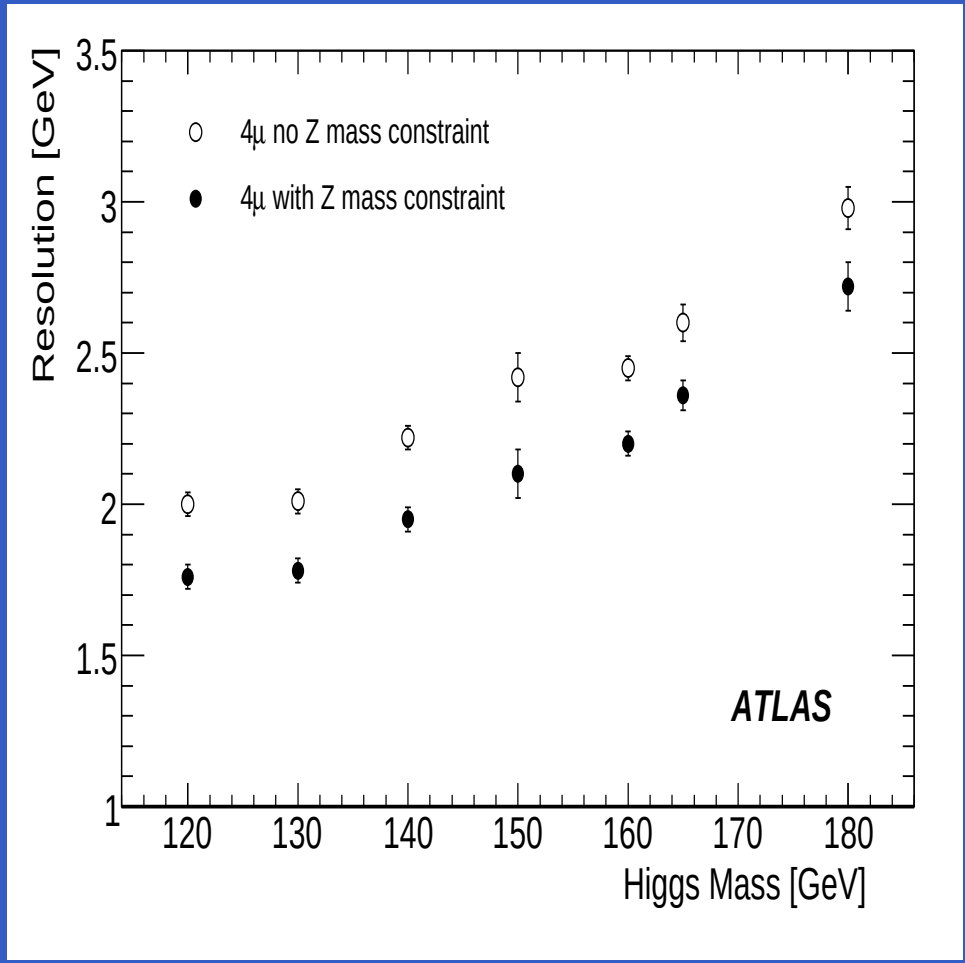
Signal (top) and background (bottom) signal selection efficiencies in %.

VBF+GF $H \rightarrow ZZ^{\star} \rightarrow 4\ell$: 4ℓ Mass in 30fb^{-1}



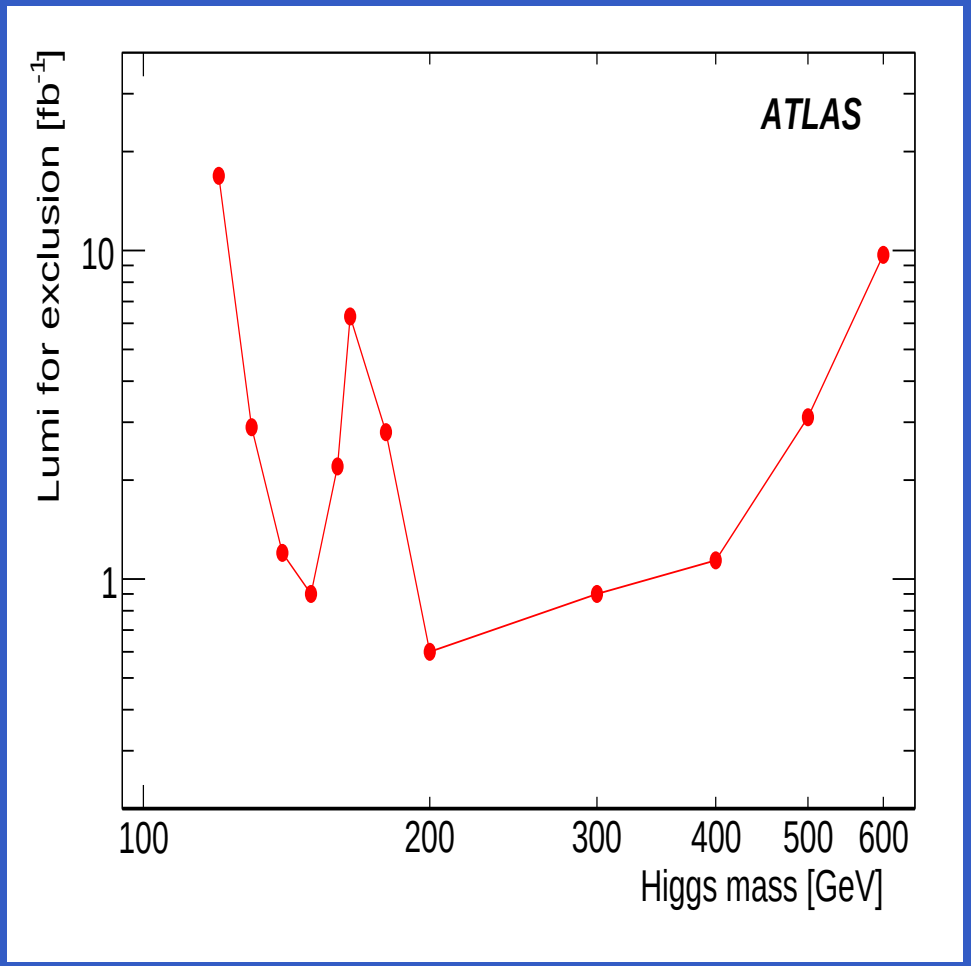
VBF+GF $H \rightarrow ZZ^{\star} \rightarrow 4\ell$: Mass Resolution

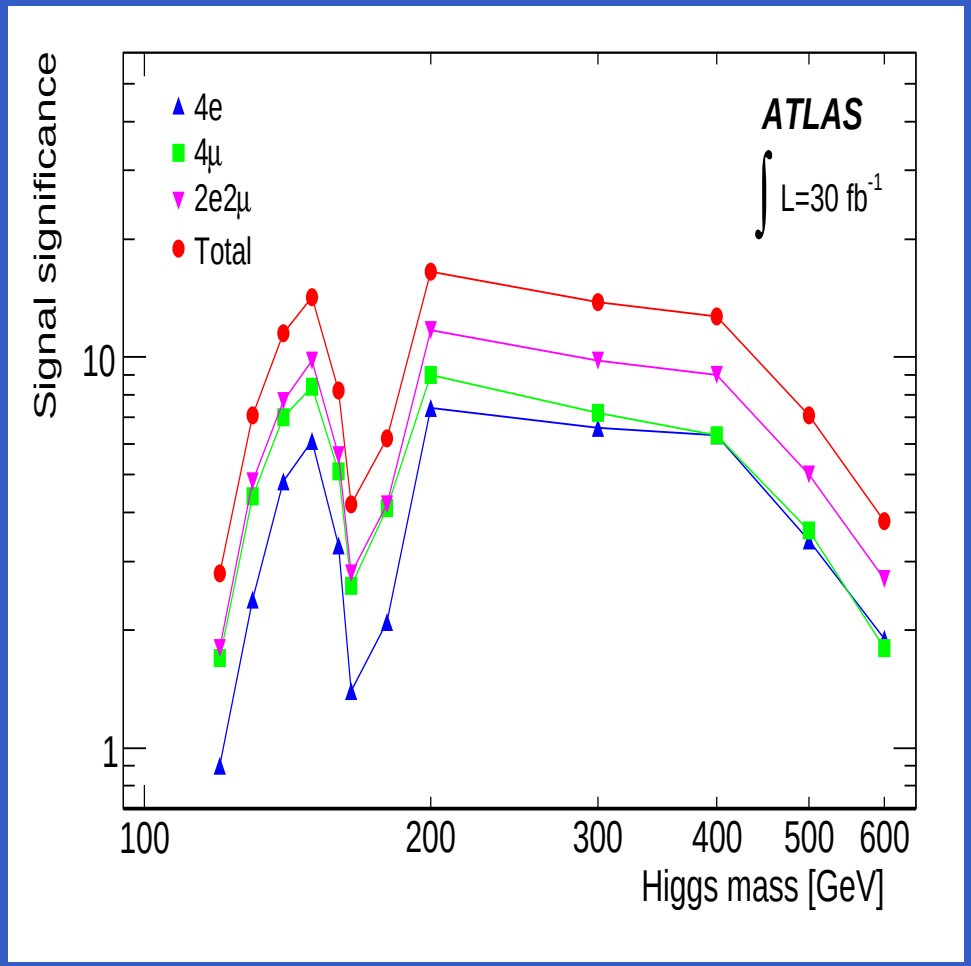




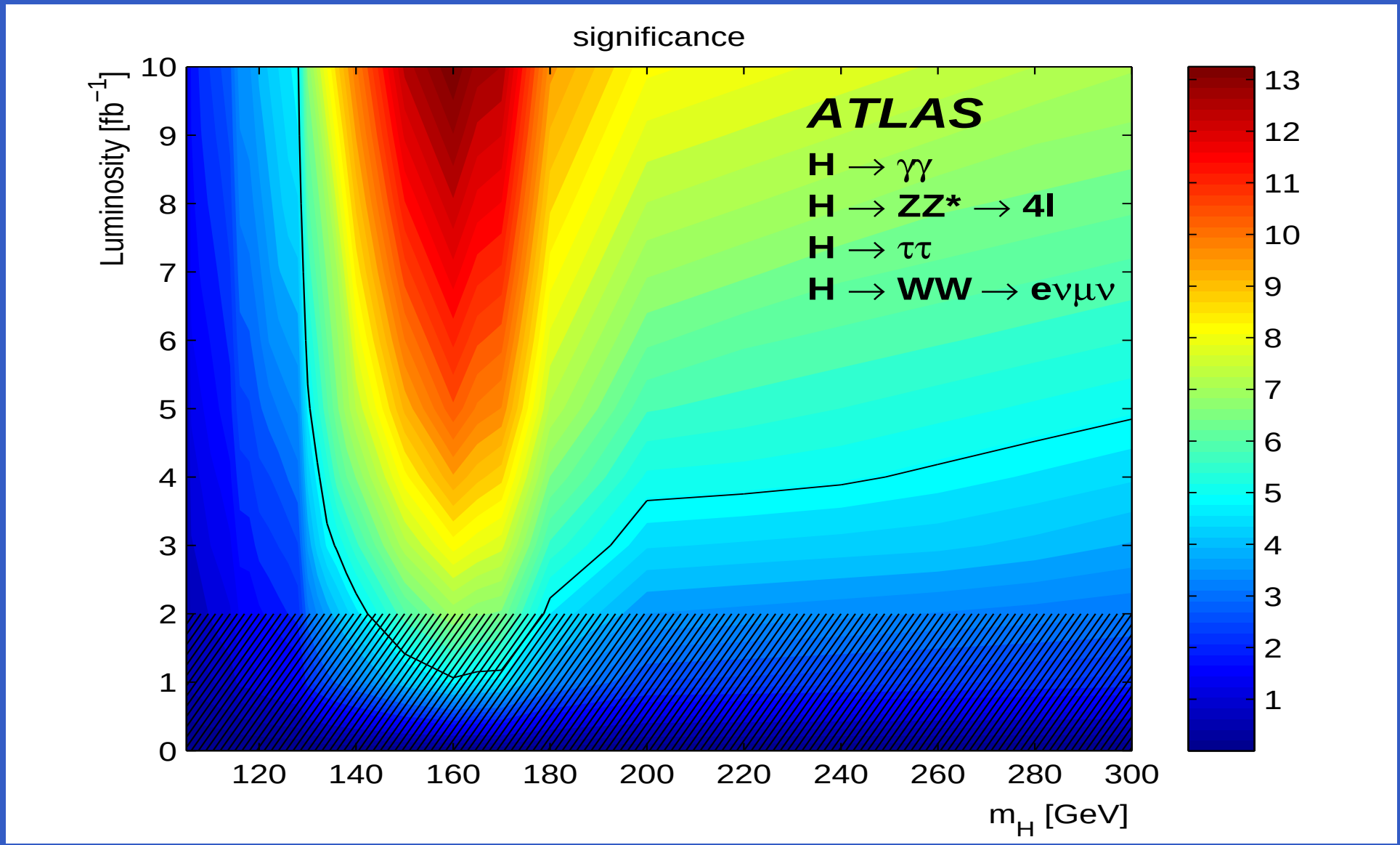
$4e$ mass resolution (left) and 4μ mass resolution (right)

VBF+GF $H \rightarrow ZZ^{\star} \rightarrow 4\ell$: Exclusion and Signifi cance



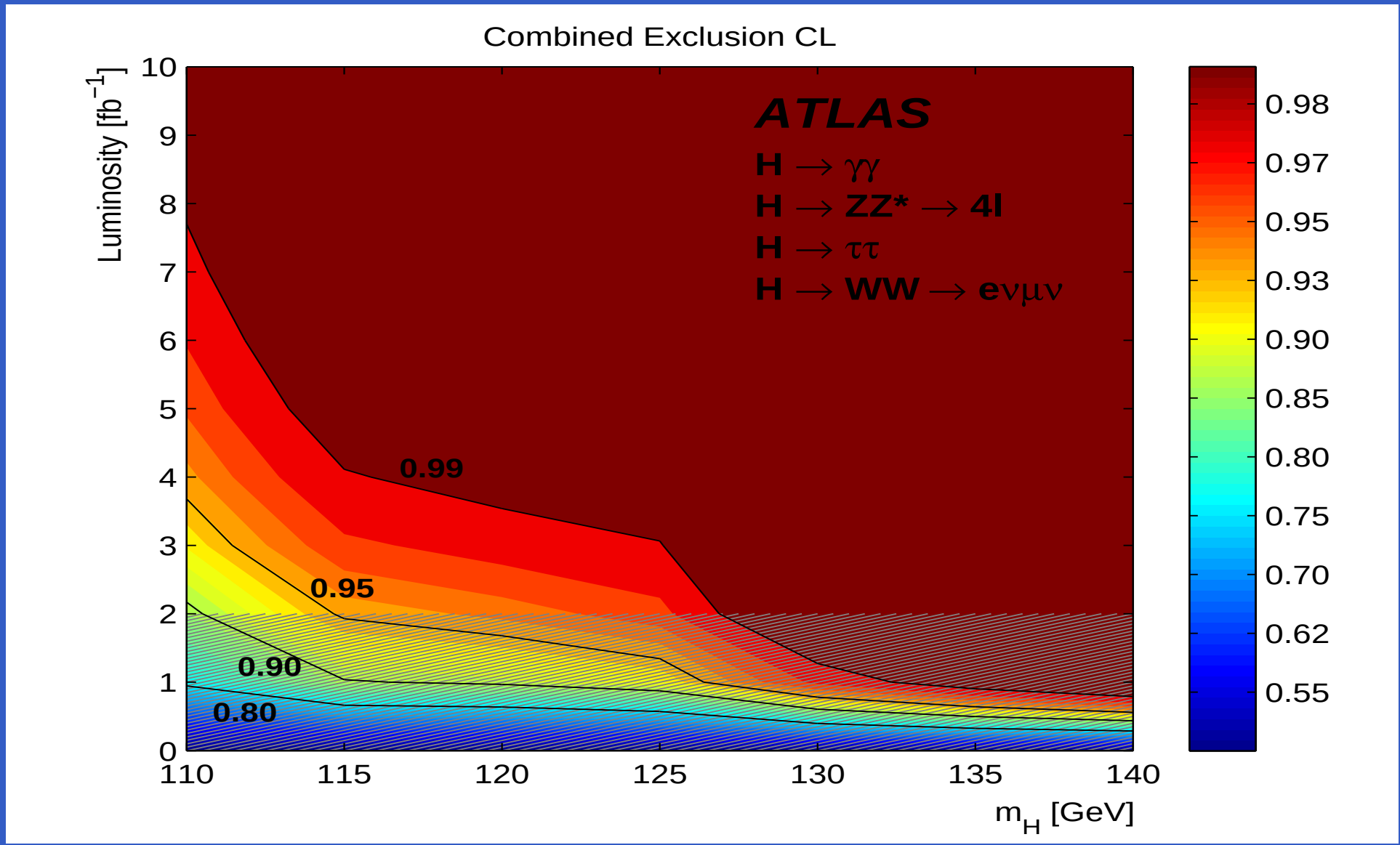


Outlook: Discovery Potential



Significance v. luminosity v. Higgs mass for a statistical combination of $\gamma\gamma$, $\tau^+\tau^-$, $ZZ^\star$, and $WW^\star$ channels. The shaded region indicates where the statistical procedure breaks down.

Outlook: Exclusion Potential

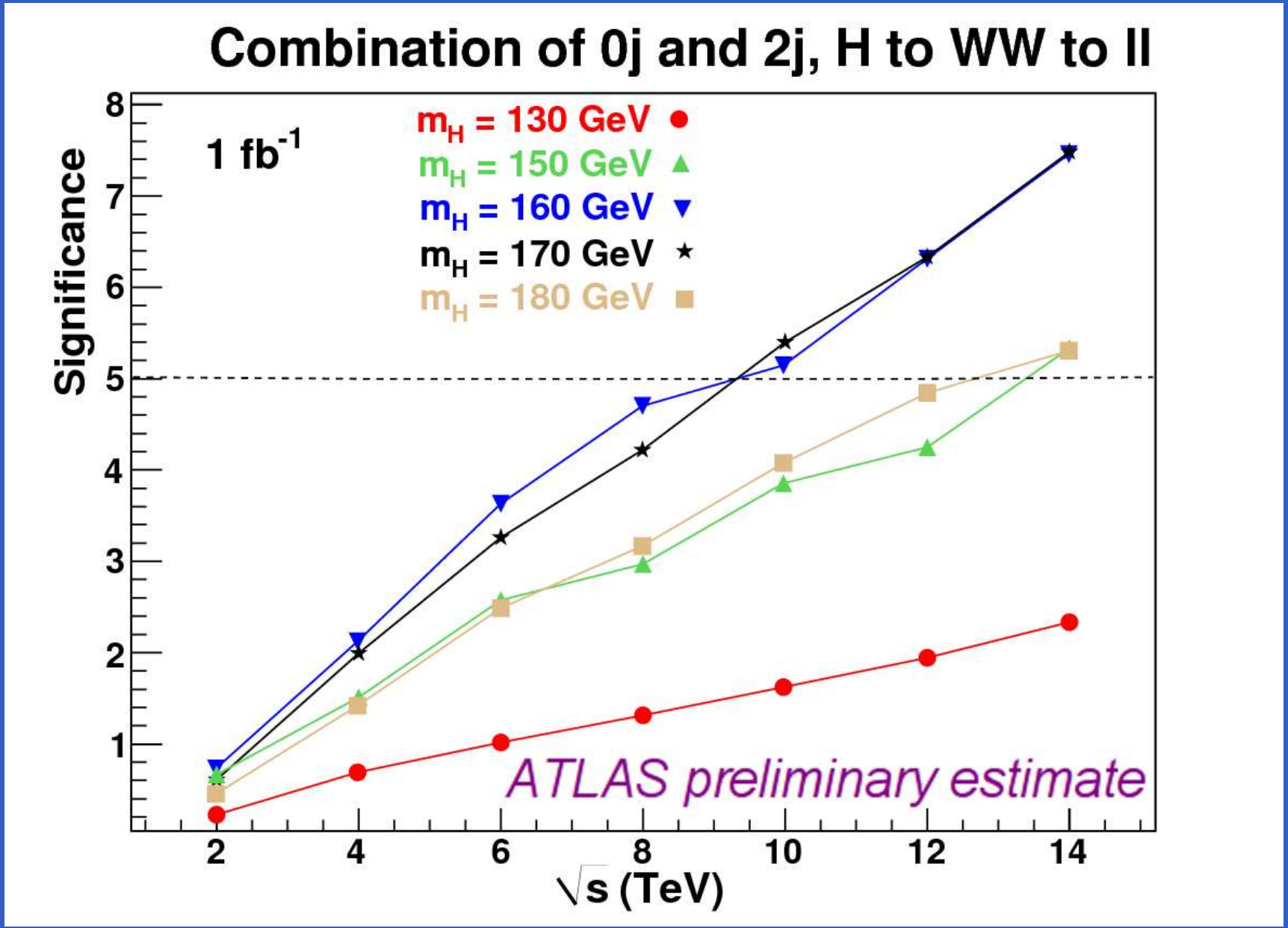


Exclusion C.L. v. luminosity v. Higgs mass for a statistical combination of $\gamma\gamma$, $\tau^+\tau^-$, $ZZ^\star$, and $WW^\star$ channels. The shaded region indicates where the statistical procedure breaks down.

Conclusions

- The ATLAS high mass Higgs results are presented assuming 10pb^{-1} for $H \to WW^{\star}$ and 30pb^{-1} for $H \to ZZ^{\star}$ and $\sqrt{s} = 14$ TeV.
- The main backgrounds are diboson production WW and ZZ and $t\bar{t}$ (also W+jets, WW+jets,...).
- Discriminating variables are
  - GF $H \to WW^{\star}$: $\Delta\phi_{\ell\ell}$, $p_T^{\ell ell}$ and m_T.
  - VBF $H \to WW^{\star}$: b tag weight and tag jet kinematics.
  - GF+VBF $H \to ZZ^{\star}$: lepton isolation and IP significance
- We have discovery potential after a few fb^{-1} for a Higgs mass near $2m_W$.
- We have exclusion potential for a large fraction of the high mass Higgs range after a few fb^{-1}.
- Scale to lower CME? See the following slide.....

Final Comment: Scaling to Lower CME



Fast Simulation and Simplified Analysis