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on behalf of the
ATLAS collaboration

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Light H+ searches in the Hadronic Mode with ATLAS

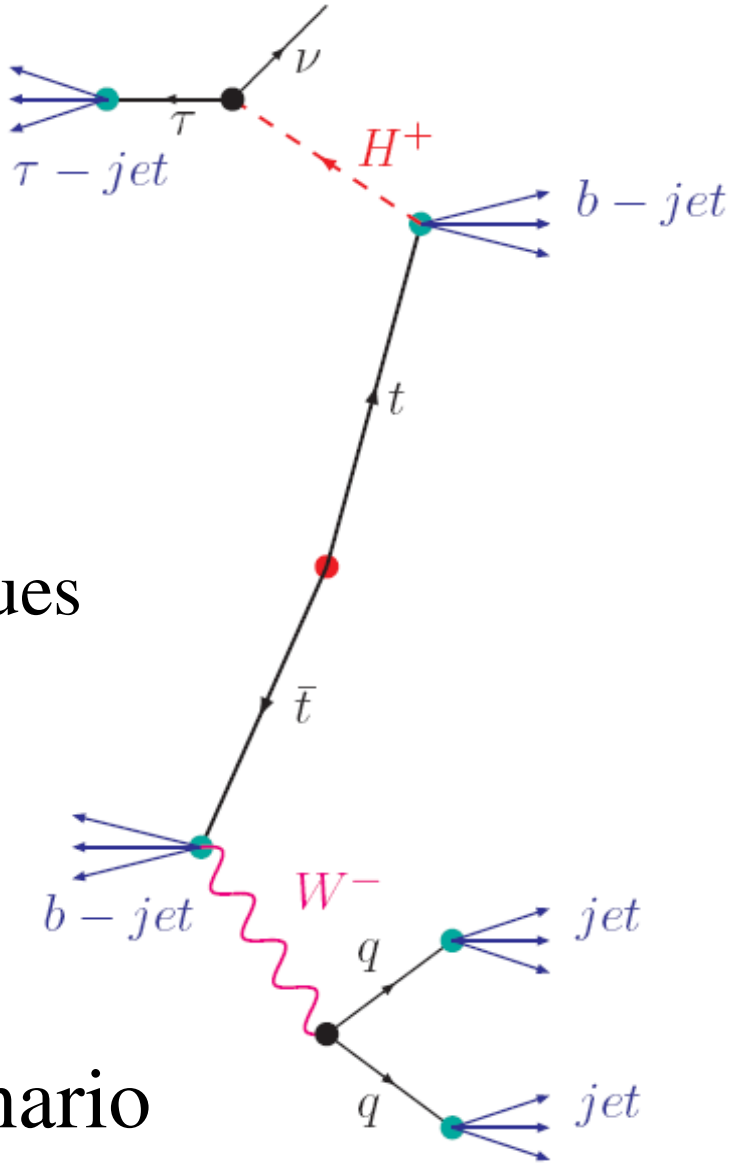
Charged Higgs 2008
Uppsala, September 18th

Outline

- Introduction
- Trigger
- Analysis
- Discovery and Exclusion Contours
- Summary

Introduction: Signal

- Light H^+: $m_{H+} < m_t$
- Production: pp → ttbar → H^+bWb
- Decay: $H^+ \rightarrow \tau\nu$
  - BR≈1 except for very small tanβ values
- In this study: $\tau \rightarrow$ hadr. & W → jj
  - BR(W → jj) = 0.676
  - BR ($\tau \rightarrow$ hadr.)= 0.648
- All plots presented for m_h-max scenario



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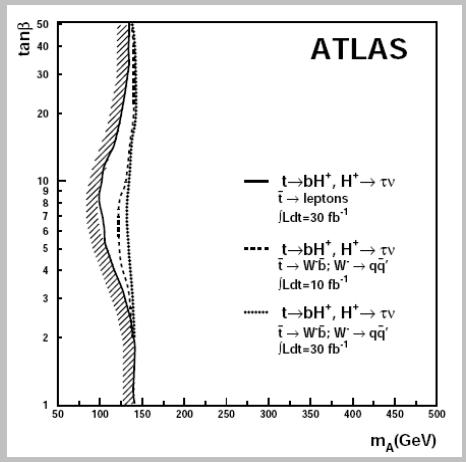
Previous Study:
ATLAS-PHYS-2003-038
using fast detector simulation



Mass [GeV]	Cross section [pb]
90	38.4
110	27.1
120	21.4
130	15.7
150	5.9

Cross-section for tanβ=35

Introduction: Background

- Backgrounds considered:
  - ttbar (all decays) ← Including decay to τ(had)νbqqb, most important background
  - Single top
  - W+jets
  - QCD dijets ← Important due to huge (~3×10^8 fb) cross-section
    - pT of 140-1120 GeV

Introduction: Simulation

- Signal: Pythia interfaced to TAUOLA
  - 5 mass-points: 90, 110, 120, 130, 150 GeV
- Background: MC@NLO (ttbar), Herwig (QCD), AcerMC (single top), Alpgen+Herwig (W+jets)
- 14 TeV centre-of-mass
- Full simulation of the ATLAS detector
- No pile-up

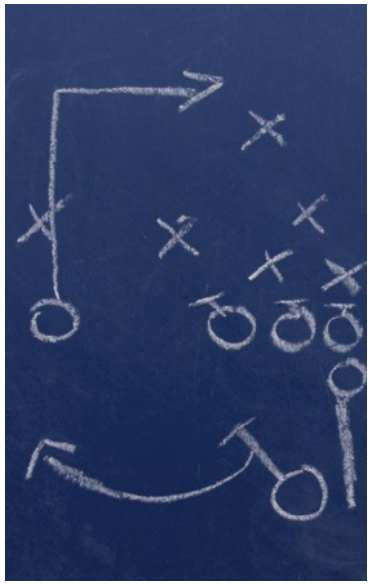
Trigger

- Two options considered, depending on instantaneous luminosity:
  - $L=10^{31}$: tau20i+xe30 or tau15i+xe20+3jet20
  - $L=10^{33}$: tau35i+xe50 or tau35i+xe40+3jet20

  (see talks by Chris, Frank and Richard)

- All results in this talk obtained assuming the 10^{33} trigger menu.
- Only about 9-17 % of signal events survive the trigger

Analysis Strategy

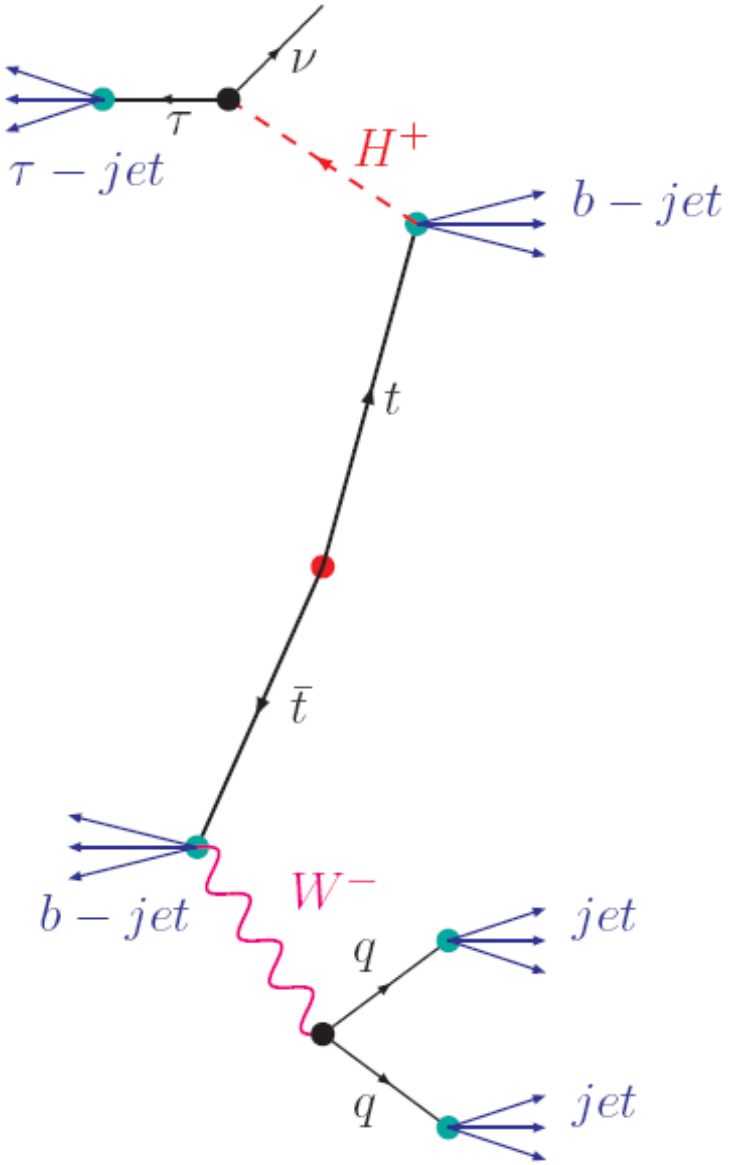


- First set of cuts
  - Select events agreeing with signal F.S.
- Second set of cuts
  - Reduce QCD background
- Likelihood
  - Discriminate between signal and SM-like ttbar background
- Reconstruct H^+ Transverse Mass
  - Calculate Significance using shape-based Profile Likelihood Method

Selection Cuts I

- Exactly 1 τ-tagged jet
  - p_T>25 GeV (see talk by Aldo)
- Exactly 2 b-tagged jets

  (see talk by Giacinto)
- At least 2 non b-tagged jets
  - Cone alg. Radius = 0.4
  - p_T>15 GeV
- No isolated *e* or μ
- E_T^{miss}>30 GeV



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Channel	Cuts I Eff.
H+ 90 GeV	13%
H+ 110 GeV	11%
H+ 120 GeV	11%
H+ 130 GeV	11%
H+ 150 GeV	9%
tt ≥ 1 e/μ/τ	2%
tt hadronic	3%
single top	0.8%
W+jets	0.5%
QCD	0.0002%

Selection Cuts II

- W and top reconstruction
  - W: pair of non-b jets with inv. mass closest to W mass
    - $|m_W^{rec} - m_W| < 30$ GeV
  - Top: W_{rec} + b jet that gives inv. mass closest to top mass
    - $|m_{top}^{rec} - m_{top}| < 40$ GeV
- $\Delta\varphi\,(p_T^{top1}, p_T^{top2}) > 2.5$ $\qquad \vec{p}_T^{\,top2} = \vec{p}_T^{\,b} + \vec{p}_T^{\,\tau jet} + \vec{p}_T^{\,miss}$
- $p_T^{\text{hardest top}} / p_T^{\text{softest top}} < 2$

Selection Cuts II

Channel	X-sec [fb]
H+ 90 GeV	146
H+ 110 GeV	117
H+ 120 GeV	101
H+ 130 GeV	86
H+ 150 GeV	31
tt ≥ 1 e/μ/τ	336
tt hadronic	16
single top	17
W+jets	30
QCD	-

Order of magnitude larger than other backgrounds.

No MC events remaining!

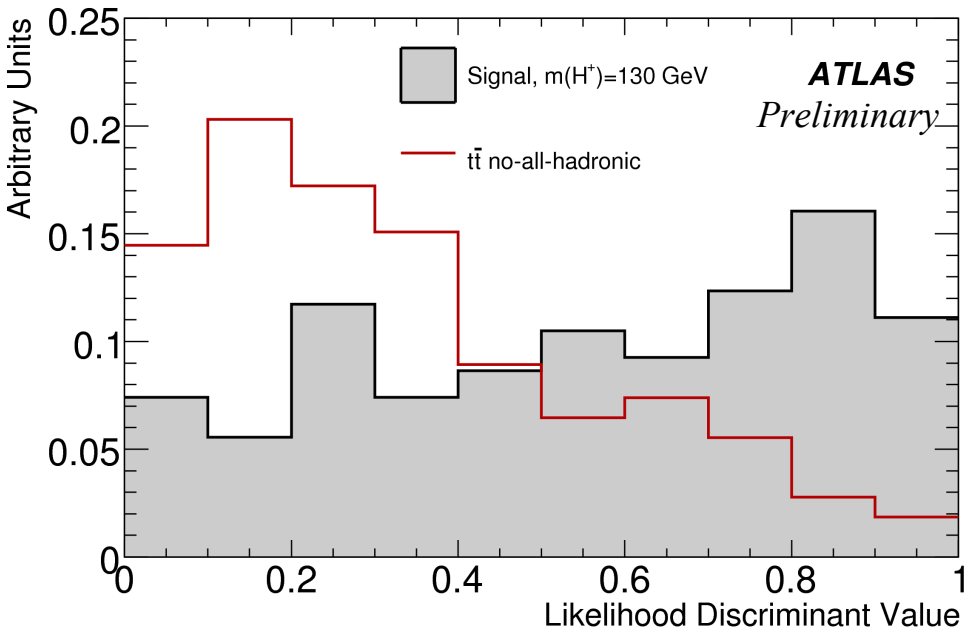
Cross-section: tanβ=20 for signal. SM values for background

Likelihood

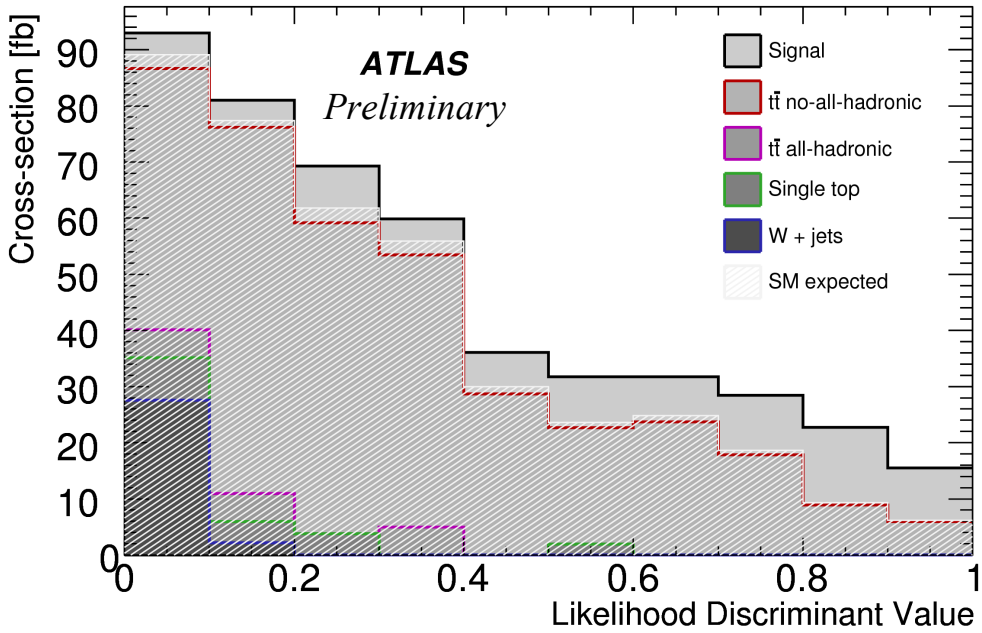
- 2-class likelihood with ttbar (≥1 lepton) as only background class
- Variables chosen to reflect $m_{H+} > m_W$ and the difference in τ polarization:
  - I. R1=pT(leading track of tau)/pT(tau)
  - II. 1-cos(Δφ(Tau,pTmiss))
  - III. 1-cos(Δφ(H^+_{rec}, b-jet[H^+])) (b-jet[H^+]: b-jet on H^+ side)
  - IV. (M(tau,b-jet[H^+])) x ΔR(tau,b-jet[H^+])
  - V. pT(tau)/pT(b-jet[H^+])
  - VI. M(tau,b-jet[H+])
  - VII. ΔR(tau,b-jet[H+])

Likelihood

- Cut on likelihood distribution
  - LH>0.6 (LH>0.8 for 150 GeV mass-point)



LH distribution for signal (m_{H+} = 130 GeV) and ttbar background normalized to unit area



LH distribution for signal and all backgrounds stacked, normalized to 10 fb^{-1}. m_{H+}=130 GeV and tanβ=20

Likelihood

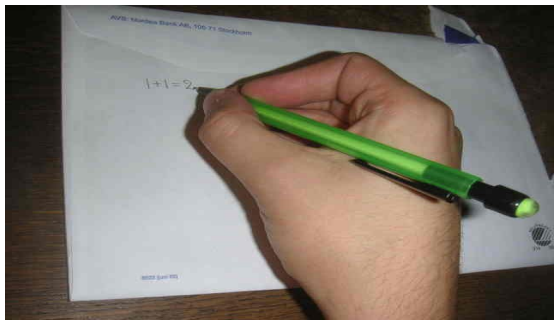
- Cut on likelihood distribution
  - LH>0.6 (LH>0.8 for 150 GeV mass-point)

	Signal eff.	**tt ≥ 1 e/μ/τ eff.**
H+ 90 GeV	41%	19%
H+ 110 GeV	46%	19%
H+ 120 GeV	47%	16%
H+ 130 GeV	49%	18%
H+ 150 GeV	46%	10%

Likelihood efficiency for signal and ttbar (≥1 lepton). Remaining background found to have negligible contribution

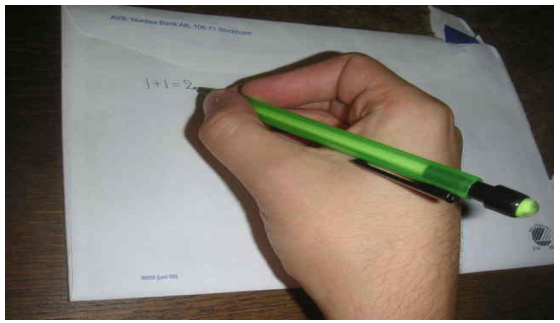
Is QCD really gone?

- Ran out of MC events quite quickly
  - Huge cross-section: can never hope to have sufficient full-simulation statistics
- ➔ Estimate...
  - Will ttbar really be the dominant background?



Is QCD really gone?

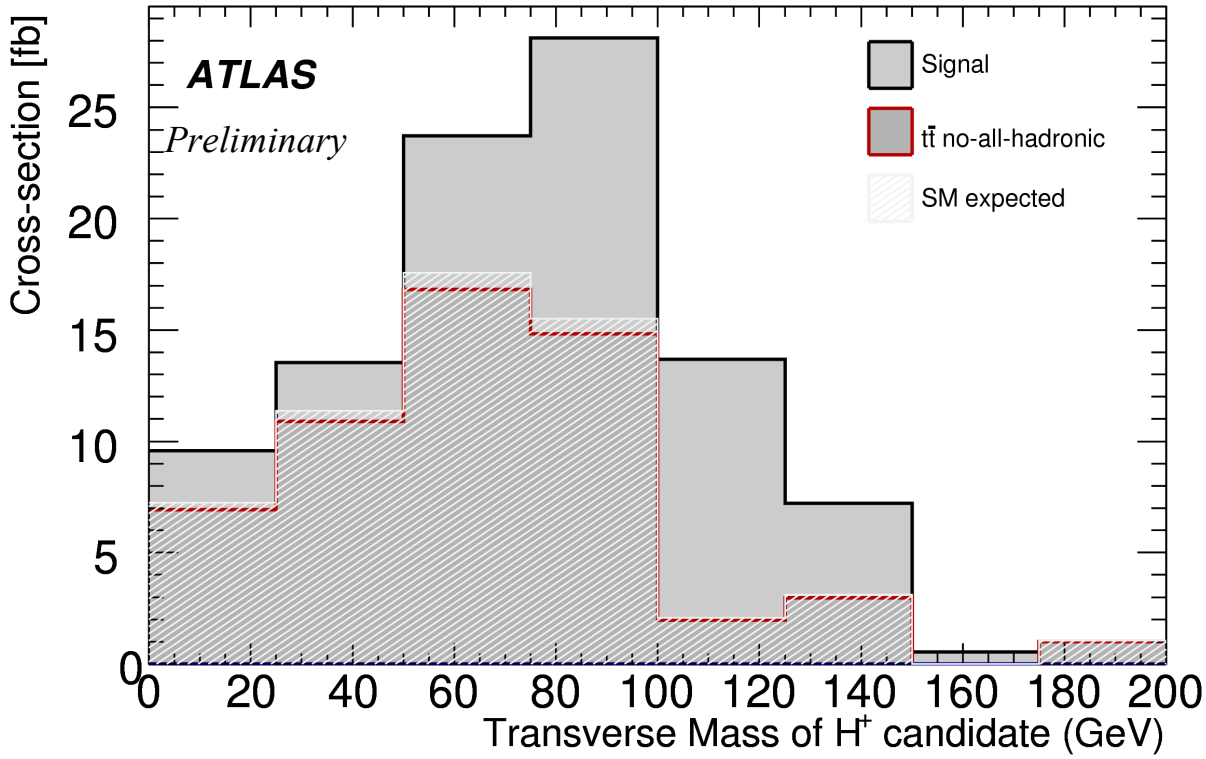
- Assume efficiency for QCD **same** as for ttbar for cuts where statistics too low: would get ~100 fb* after LH cut
- ➔ Same order of magnitude as ttbar (60 fb*)
- Extremely conservative assumption, since Cuts II were explicitly designed to identify ttbar / suppress QCD
  - Will in fact probably be several times lower...
- ➔ QCD should not dominate over the ttbar background



*: for a m_{H+} = 130 GeV Likelihood cut

Transverse Mass

- Transverse H^+ mass calculated for events surviving LH cut

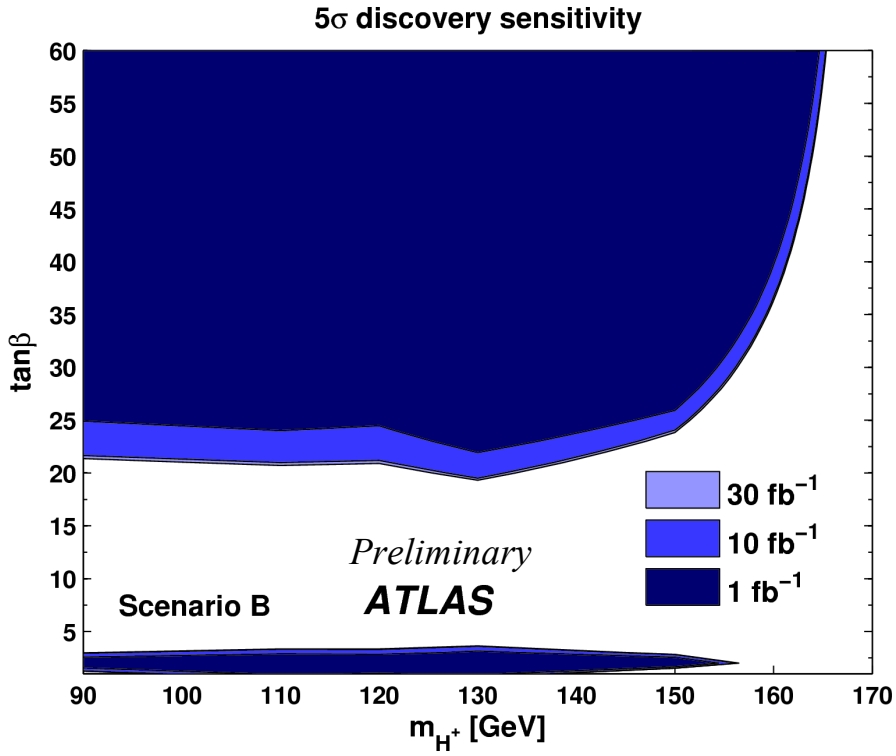


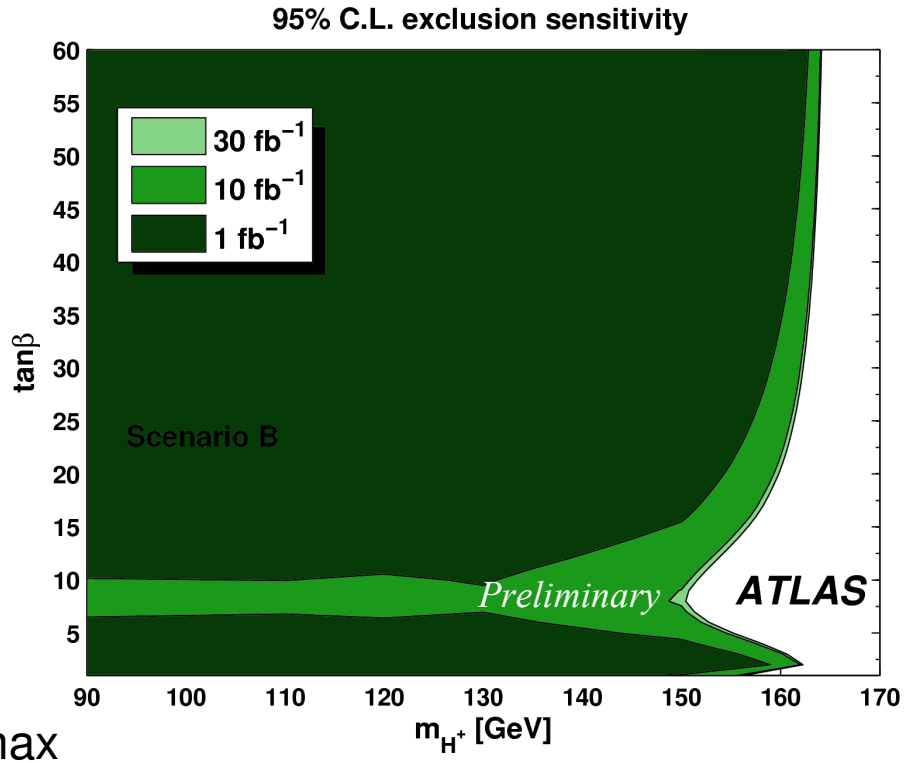
m_{H+}=130 GeV
tanβ=20

- Significance calculated using shape-based Profile Likelihood Method applied on transverse mass histogram (see Ofer's talk)

Discovery / Exclusion

- Systematics assumed: signal 24%, background 10%
  (see Trevor's talk)
- Statistical uncertainties due to limited MC very important





m_h-max

Summary

- ttbar→H^+bWb, with H^+→τ(had)ν and W→qq has been studied with full simulation for ATLAS
- Two sets of cuts and a likelihood used to discriminate against a multitude of backgrounds
- Discovery contour reaching down to ~22 in tanβ and for masses up to 150 GeV
- Exclusion possible for all tanβ values for masses up to ~150 GeV

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Backup Slides

Selection Likelihood: Calculation

- Likelihood discriminant for an event:

$$\mathcal{L} = \frac{S(x_1, x_2, ...)}{S(x_1, x_2, ...) + B(x_1, x_2, ...)}$$

Best discriminator

$$\approx \frac{\prod_i S_i}{\prod_i S_i + \prod_i B_i} = \frac{\prod_i S_i/B_i}{\prod_i S_i/B_i + 1} = \frac{\exp\left(\sum_i (\ln \frac{S_i}{B_i})\right)}{\exp\left(\sum_i (\ln \frac{S_i}{B_i})\right) + 1}$$

$$= \frac{\exp\left(\sum_i (\ln \frac{S}{B})^i_{\text{fitted}}\right)}{\exp\left(\sum_i (\ln \frac{S}{B})^i_{\text{fitted}}\right) + 1}.$$

Fitted value $\ln(P_{sig}/P_{ttbar})$

Neglect correlations

- A 2D-Likelihood is used, with ttbar no-all-hadronic as background (other background samples are relatively small after the previous cuts)

Efficiency I

Channel		All events	Trigger	Cuts I	Cuts II
H^+ 90 GeV	[fb]	38400	3384	442	146
	[/]		*0.088*	*0.131*	*0.331*
H^+ 110 GeV	[fb]	27100	2871	307	117
	[/]		*0.106*	*0.107*	*0.381*
H^+ 120 GeV	[fb]	21400	2563	275	101
	[/]		*0.120*	*0.107*	*0.369*
H^+ 130 GeV	[fb]	15700	2136	234	86
	[/]		*0.136*	*0.109*	*0.368*
H^+ 150 GeV	[fb]	5870	982	92	31
	[/]		*0.167*	*0.093*	*0.343*
$t\bar{t} \geq 1\ e/\mu/\tau$	[fb]	$4.52 \cdot 10^5$	56300	962	336
	[/]		*0.125*	*0.017*	*0.349*
$t\bar{t}$ hadronic	[fb]	$3.81 \cdot 10^5$	1746	47	16
	[/]		*0.005*	*0.027*	*0.333*
single top	[fb]	112500	7700	63	17
	[/]		*0.068*	*0.008*	*0.277*
W + jets	[fb]	277800	15500	84	30
	[/]		*0.056*	*0.005*	*0.353*
QCD dijet	[fb]	$3.2 \cdot 10^8$	$3.18 \cdot 10^5$	55	–
	[/]		*0.001*	$1.7 \cdot 10^{-4}$	–

ATLAS *Preliminary*

Expected cross-section and relative efficiency up to Cuts II. tanβ=20 has been used for signal and SM cross-section for backgrounds.

Efficiency II

Expected cross-section and efficiency after LH cut and after a cut on m_T. Only ttbar expected to contribute at this point. tanβ=20 used for signal cross-section.

ATLAS *Preliminary*

Channel		Cut	Signal		$t\bar{t} \geq 1$	$e/\mu/\tau$
			[fb]	[/]	[fb]	[/]
H^+	90 GeV	LH > 0.6	60.2	*0.411*	64.1	*0.191*
		mT >50 GeV	39.2	*0.652*	36.2	*0.565*
H^+	110 GeV	LH > 0.6	53.6	*0.458*	62.1	*0.185*
		mT >60 GeV	35.1	*0.655*	31.0	*0.500*
H^+	120 GeV	LH > 0.6	47.2	*0.466*	53.8	*0.160*
		mT >60 GeV	36.4	*0.770*	32.1	*0.596*
H^+	130 GeV	LH > 0.6	42.0	*0.488*	58.9	*0.175*
		mT >65 GeV	35.1	*0.835*	27.9	*0.474*
H^+	150 GeV	LH > 0.8	14.4	*0.459*	32.1	*0.095*
		mT >75 GeV	9.7	*0.671*	11.4	*0.355*

Systematic Uncertainties

Systematic uncertainties used

Source of Uncertainty	Uncertainty and/or Resolution Function
τ energy resolution	$\sigma = 0.45 \times \sqrt{E}$
τ energy scale	-5% $+5\%$
τ-tagging efficiency	$\pm 5\%$
Jet energy resolution	$\sigma = 0.45 \times \sqrt{E}$ for $\lvert\eta\rvert < 3.2$ $\sigma = 0.63 \times \sqrt{E}$ for $\lvert\eta\rvert > 3.2$
Jet energy scale	$+7\%$ for $\lvert\eta\rvert < 3.2$ $+15\%$ for $\lvert\eta\rvert > 3.2$
	-7% for $\lvert\eta\rvert < 3.2$ -15% for $\lvert\eta\rvert > 3.2$
b-tagging efficiency	$\pm 5\% \varepsilon_{btag}$
b-tagging light jet rejection	-10% $+10\%$
μ energy resolution	$\sigma = 0.011/P_T \oplus 0.00017$
μ energy scale	-1% $+1\%$
μ efficiency	$\pm 1\%$
e energy resolution	$\sigma = 0.0073 \times E_T$
e energy scale	-0.5% $+0.5\%$
e efficiency	$\pm 0.2\%$
Correction to missing energy	Indirect effects following from the other uncertainties
Luminosity	$\pm 3\%$

% change in cross-section

ATLAS *Preliminary*

Systematic Uncertainty	1 S	1 B
τ Energy Resolution	-2	+3
τ Energy Scale	-2 -5	+5 -5
τ-tagging Efficiency	-5	-2
Jet Energy Resolution	-2	-3
Jet Energy Scale	-9 -5	+12 -5
b-tagging Efficiency	0	-14
b-tagging Rejection	-7 +7	+10 -2
μ Energy Resolution	0	0
μ Energy Scale	0 0	0 0
μ Efficiency	0	0
e Energy Resolution	0	0
e Energy Scale	0 0	0 0
e Efficiency	0	0
Luminosity	-3 +3	-3 +3