ATLAS discovery prospects for the charged Higgs in di-lepton ttbar events ($H^+ \rightarrow \tau_{lep} \nu$ final state)

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"Prospects for Charged Higgs Discovery at Colliders"

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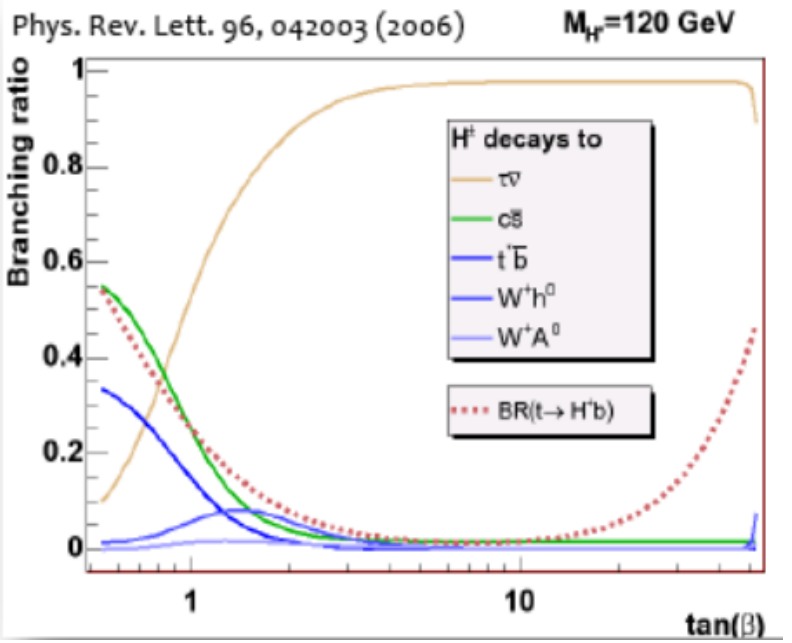
On the behalf of the ATLAS Collaboration

- introduction
- analysis techniques
- systematics and upper limit estimates
- 10 TeV vs 7 TeV MC studies
- results and conclusions

McGill

Introduction

- H^+ production dominated by top decays
  - if both W and H decay fully leptonically, we have two leptons and two b-jets in the final state
  - easy to trigger on, low QCD backgrounds
  - mass reconstruction difficult due to neutrinos
- main backgrounds:
  - ttbar and single top (mainly tW)
- we present a simple cut based analysis, suitable for early data, that doesn't rely on b-tagging or Missing E_T
- we should expect to be competitive with current Tevatron results with ~1 fb^{-1}
  - more detail can be found in two public notes:
    - ATL-PHYS-PUB-2010-006
    - ATL-PHYS-PUB-2010-009



$$BR(b\bar{b}W^-H^+ \to b\bar{b}l^-\bar{\nu}l^+\bar{\nu}\nu\nu) \approx 7\%$$

Approximate Tevatron upper limits (D0, 1fb^{-1}):

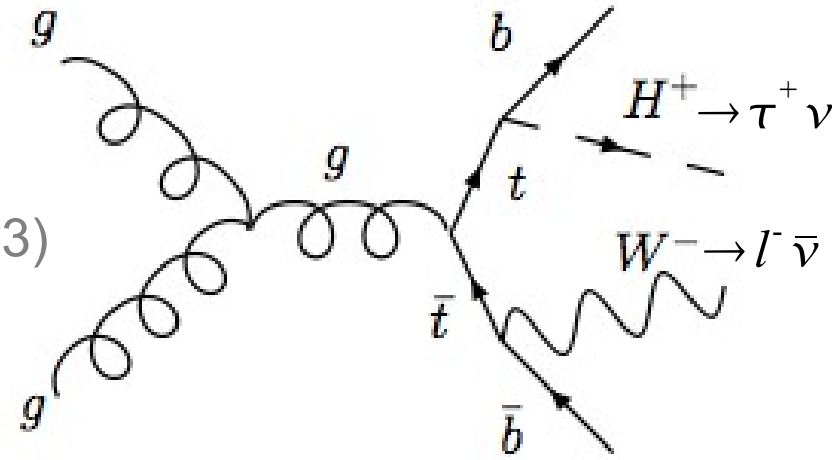
m_{H^+} in GeV	Max$[BR(t \to bH)]$
90	15%
110	15%
130	17%
150	19%

Analysis overview

Basic Selection (ttbar events):

- two oppositely charged leptons with p_T > 10 GeV, $|\eta|$ < 2.5
  - p_T cuts motivated by trigger rates: 10 GeV single lepton triggers used

  (e15, mu13 expected to be unprescaled through L_{inst} = 1e32 $cm^{-2}s^{-1}$ running)
  - offline cut at 20 GeV for leading, 10 GeV for trailing
- at least two jets with p_T > 15 GeV, $|\eta|$ < 5.0
  - the two jets with highest b-weights are assumed to come from top quark decays
  - demand only one b-tagged jet (b-weight>4.3)
- Missing E_T > 50 GeV



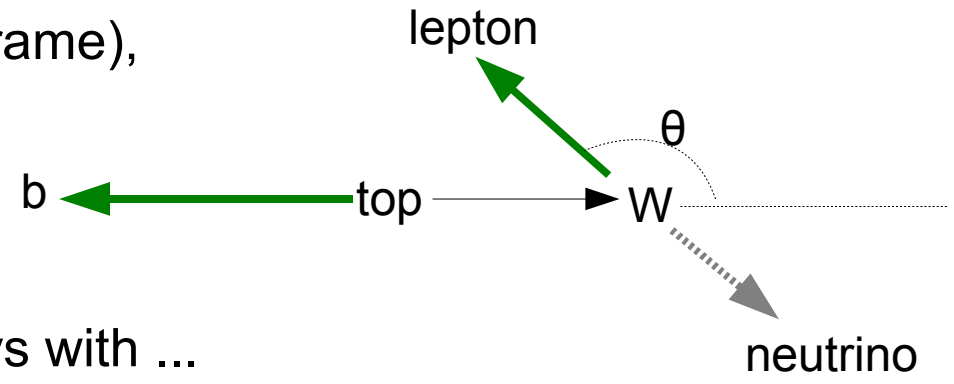
Signal Selection ($t \to bH^+$ events):

- need to take advantage of other approaches to improve signal sensitivity:
  - *W* helicity angle ($\cos\theta^*_l$)
  - generalized transverse mass (M_{T2})

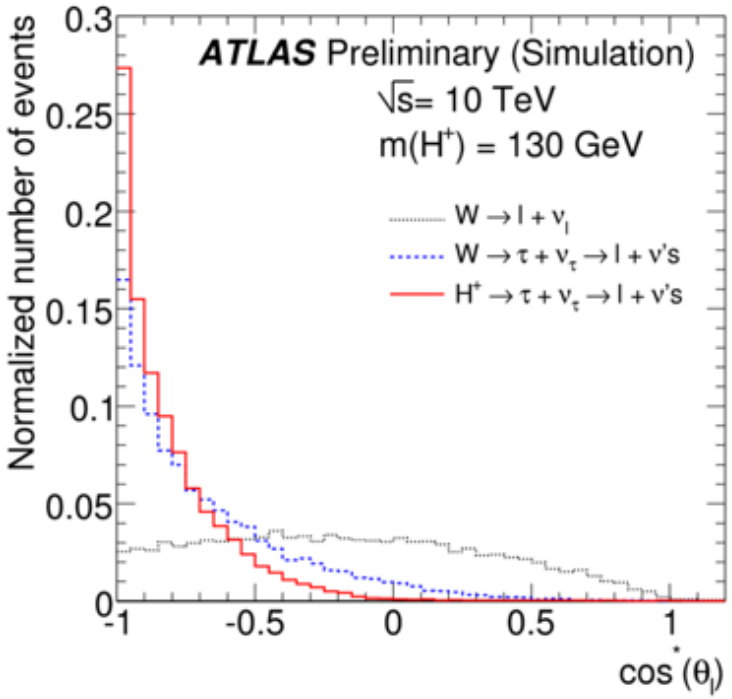
Helicity angle - $\cos\theta^*$

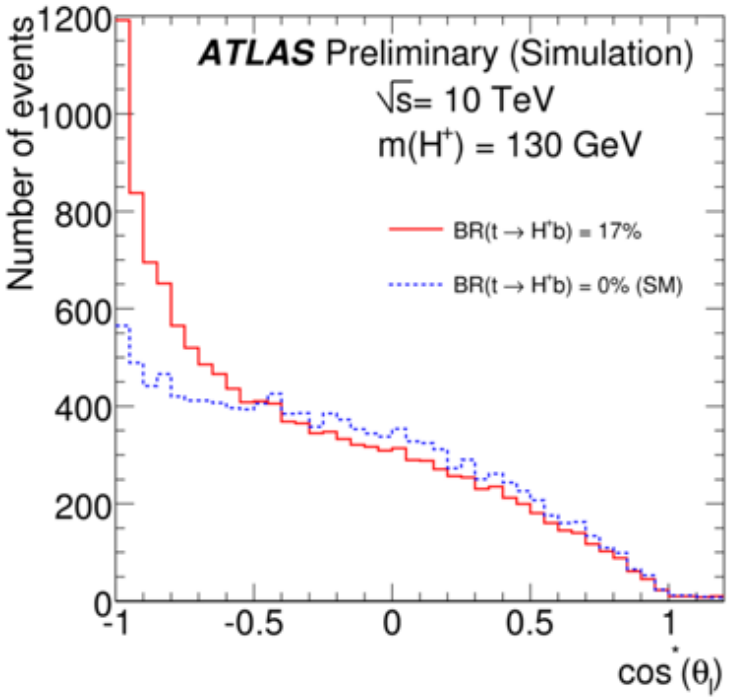
- cosine of the angle relative to 3-vector momenta of the lepton and b-jet candidate (in *W* rest frame), originating from the same top quark

$$\cos\theta_\ell^* \simeq \frac{4\, p_b \cdot p_\ell}{m_t^2 - m_W^2} - 1,$$



- distribution peaks sharply at -1 for decays with ...
  - higher mass particles (H^+)
  - taus in the decay chain (lower lepton momentum)





Generalized transverse mass - M_{T2}

- an event-by-event lower limit for the mass of the unknown particle
  - start with eight variables and six constraints
  - first use Lagrange multipliers to analytically maximize mass
    - gives M_T^H as a function of p_T^H,
    - since p_T^H is constrained, use numerical maximization to get the final result

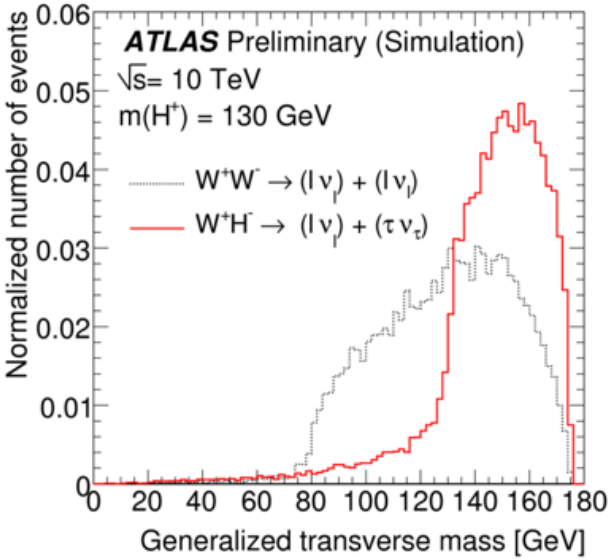
$$
\begin{aligned}
(p^{H^+} + p^b)^2 &= m_{top}^2, \\
(p^{\ell^-} + p^{\bar{\nu}_\ell})^2 &= m_W^2, \\
(p^{\ell^-} + p^{\bar{\nu}_\ell} + p^{\bar{b}})^2 &= m_{top}^2, \\
(p^{\bar{\nu}_\ell})^2 &= 0, \\
\vec{p}_T^{\,H^+} - \vec{p}_T^{\,l^+} + \vec{p}_T^{\,\bar{\nu}_\ell} &= \vec{p}_T^{\,miss}.
\end{aligned}
$$

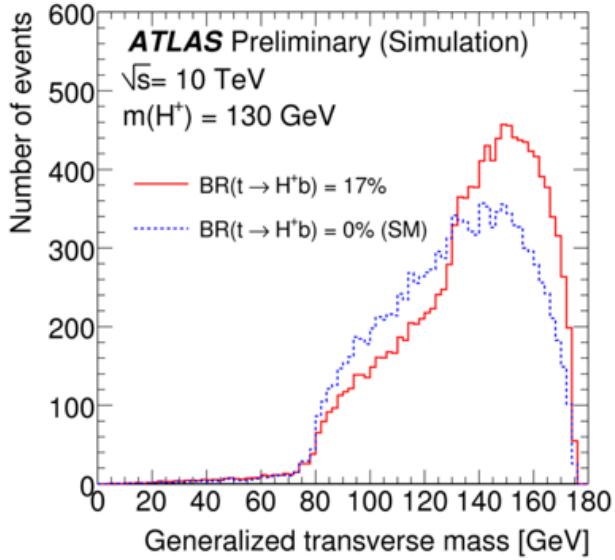
- H^+ mass bound useful if signal is observed

$$
(M_T^H)^2 = \left(\sqrt{m_{top}^2 + (\vec{p}_T^{\,H^+} + \vec{p}_T^{\,b})^2} - p_T^b \right)^2 - (p_T^{H^+})^2.
$$

$$
\vec{p}_T^{\,H^+} = \vec{p}_T^{\,miss} + \vec{p}_T^{\,l^+} - \xi(\phi),
$$

$$
m_{T2}^{H^+} = \max_{\phi} [M_T^H(\phi)].
$$





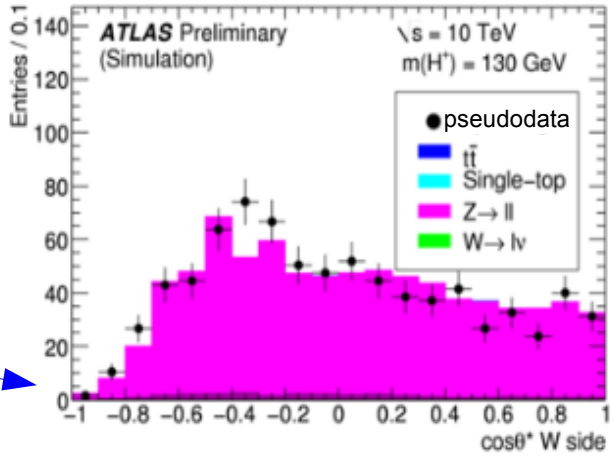
Other things worth mentioning

Four-fold ambiguity in pairing leptons and b-jets:

- for events with a clear incorrect pairing, the other solution gives the correct l-b pairs; the pair with a smaller $\cos\theta^*$ is assigned to H^+ (dubbed as the *H side*)
- for other events, the pair with the largest $\cos\theta^*$ value is assigned to W (*W side*) and its partner pair to H^+ (*H side*)

Background sideband normalization:

- number of MC events in each sideband is scaled to match data (pseudo-data shown on right)
  - m(ll), Missing E_T, b-tag, lepton flavor, $\cos\theta^*$
  - MC/data agreement is checked for each sideband

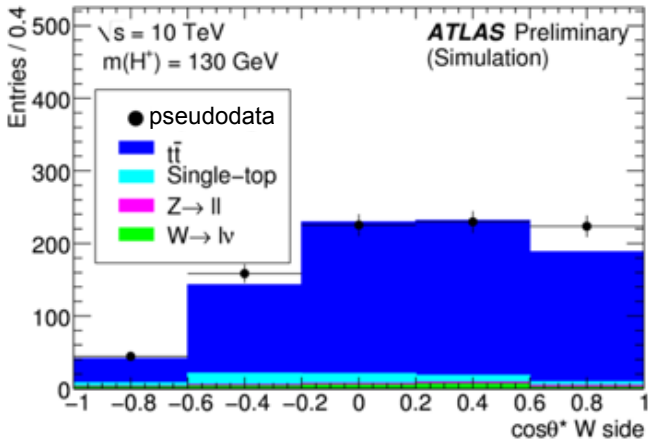


Fake lepton background rate:

- data driven method as a double check
- tag and probe approach, assuming doubly fake rate is negligible

$$\begin{bmatrix} N_{\text{tight}} \\ N_{\text{loose}} \end{bmatrix} = \begin{bmatrix} rr & rf \\ r(1-r) & r(1-f) \end{bmatrix} \begin{bmatrix} N_{\text{real}} \\ N_{\text{fake}} \end{bmatrix}$$

$$N_{\text{fakes}} = N_{\text{RF}} = \frac{N_{\text{TL}} + \frac{r-1}{r} N_{\text{TT}}}{r-f}.$$

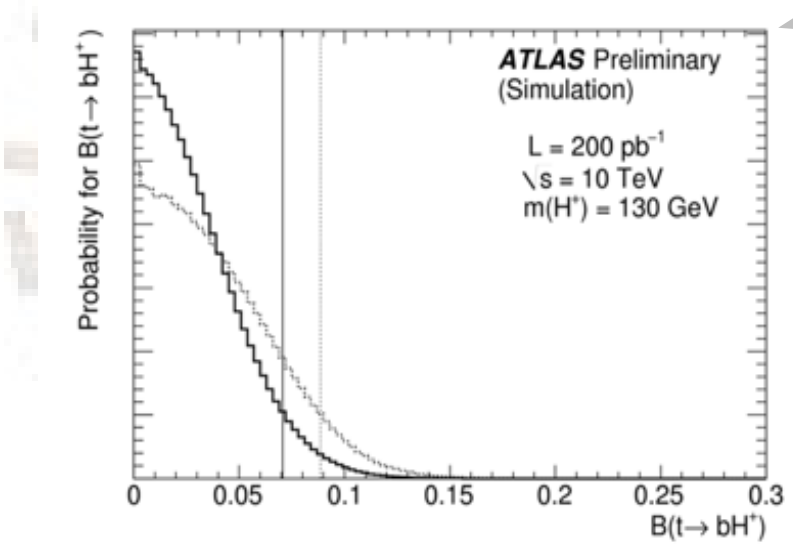


Systematics & UL setting

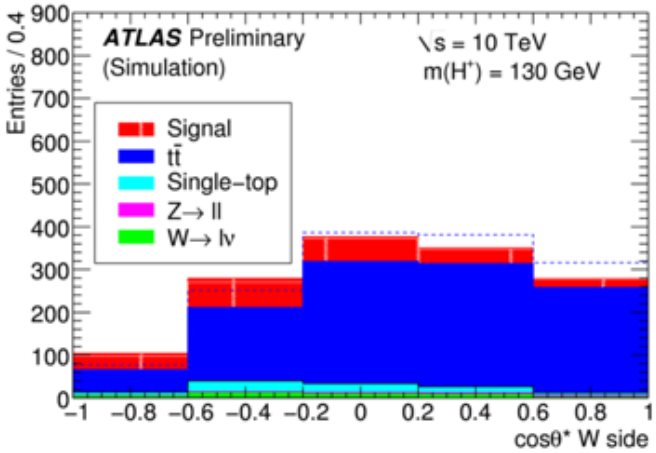
- The 95% C.L. upper limits are extracted from pseudo-experiments taking into account uncertainies on N_{obs}, N_{bg}, and ε_{sig}

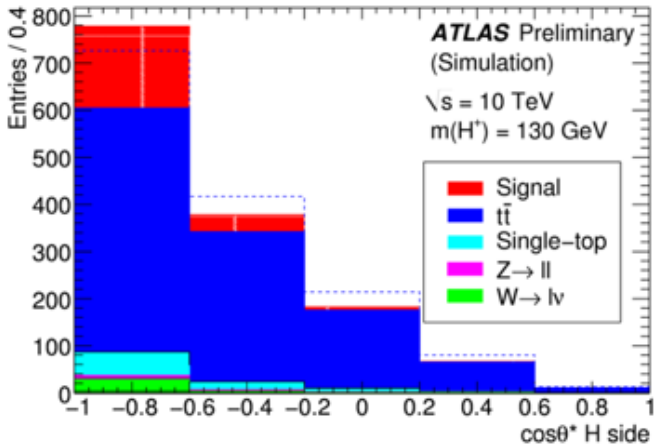
$$\mathcal{B} = \frac{N_{obs} - N_{bg}}{2 \times \sigma_{t\bar{t}} \times L_{int} \times \varepsilon_{sig}}$$

$$W_{\mathcal{B}}(N_{bg}, N_{obs}, \varepsilon_{sig}) = P(N_{bg}) \times P(N_{obs}) \times P(\varepsilon_{sig})$$



Source	Uncertainty (in %)	Effect (in %) on N_{bg}	Effect (in %) on ε_{sig}
Normalization	7	7	n/a
Trigger	1	< 1	1
Lepton ID efficiency	1	< 1	1
Lepton fake rate	1	1	1
Lepton energy scale	1	< 1	1
Jet energy scale	7-15	7	4
b-tagging efficiency	4	< 1	4
b-tagging fake rate	10	1	< 1
Total		10	6

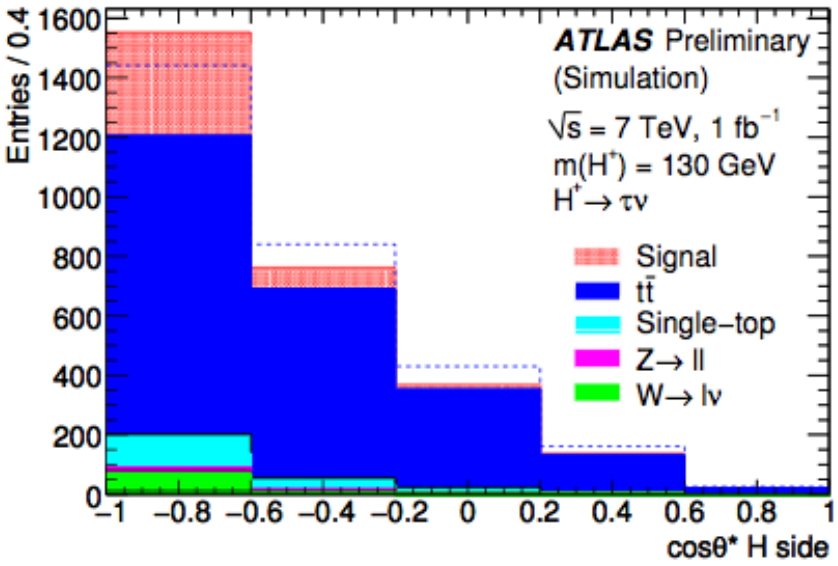




Signal count is extracted from the first bin on H^+ side: $\cos\theta^*_l < -0.6$

10 TeV vs 7 TeV MC analysis

- Public 10 TeV ATLAS note: ATL-PHYS-PUB-2010-006
  - $H^+ \to csbar$ and $H^+ \to \tau\nu$ channels only
- Public 7 TeV ATLAS note: ATL-PHYS-PUB-2010-009
  - combined note for several Higgs channels
- 7 Tev projections of the latter are based on results of the former note
  - background cross sections and PDFs are re-scaled for corresponding $\sqrt{s}$
  - target luminosity changed from 200 pb^{-1} to 1 fb^{-1} (estimated luminosity available after the first year)



Signal sensitivity for $H^+ \to \tau\nu$ at 7 TeV

H^+ mass in GeV	90	110	130	150
$\mathcal{B}(t \to bH^+)$	15%	15%	17%	19%
$\mathcal{S} = N_{sig}/\sqrt{N_{bg}}$	12.3	14.4	16.0	15.5

Sample cross sections for various LHC $\sqrt{s}$

$\sqrt{s}$ (TeV)	2	7	8	9	10	12	14
W	0.149	0.678	0.786	0.893	1.000	1.213	1.424
WW	0.061	0.597	0.728	0.863	1.000	1.273	1.568
$t\bar{t}$	0.005	0.397	0.567	0.768	1.000	1.551	2.214
$gg \to H$	0.023	0.502	0.654	0.821	1.000	1.393	1.825
$qq \to qqH$	0.019	0.502	0.657	0.830	1.000	1.405	1.856

Results and Conclusions

- with ~1 fb^{-1} at $\sqrt{s}$ = 7 TeV, prospects for the search of a light charged Higgs in dilepton ttbar events look good: ATLAS results are expected to be competitive with current Tevatron limits
  - two final state leptons yield a low non-ttbar background rate
  - data driven techniques help with background estimation
  - $\cos\theta^*_l$ helps to separate signal from SM ttbar events
  - H^+ mass limit (M_{T2}) available upon signal observation

95% C.L. Upper limits:

m_{H^+} (GeV)	$H^+ \to \tau^+\nu$ Tevatron	$H^+ \to \tau^+\nu$ ATLAS expected
90	15%	9%
110	15%	7%
130	17%	8%
150	19%	9%