Search for charged Higgs bosons in $H^+ \rightarrow Wh \rightarrow l\nu bb$ decays with the ATLAS detector

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ATLAS EXPERIMENT

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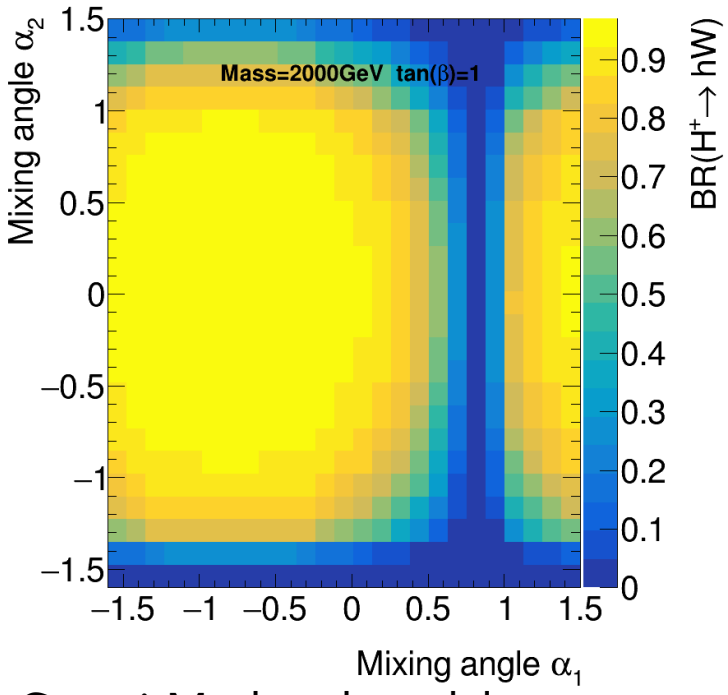
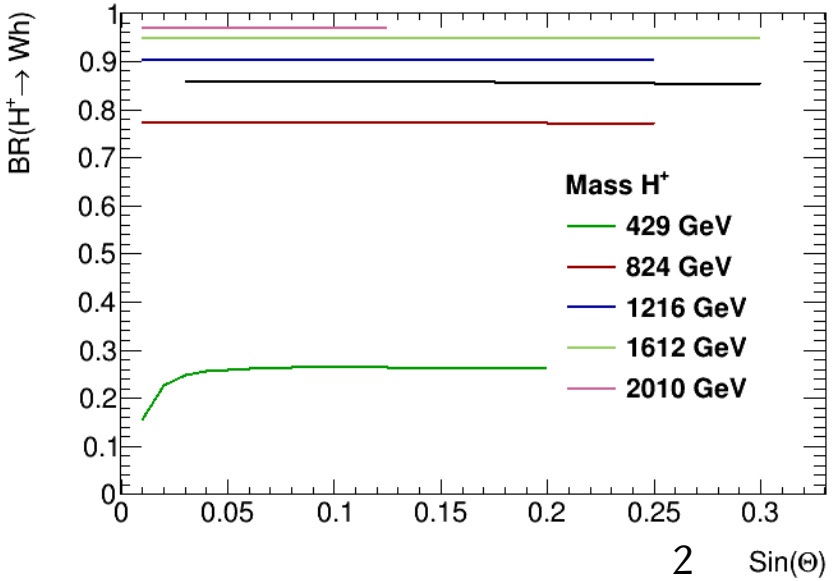
Motivation

- Several extensions of the SM predict an extended Higgs sector
  - e.g supersymmetric models
- Models with additional Higgs doublets or triplets predict electrically charged scalars H^+
- Decay $H^+ \rightarrow Wh$ (h=125 GeV SM-like Higgs) is so far not explored by ATLAS and CMS searches
  - $H^+ \rightarrow tb$ or $H^+ \rightarrow \tau\nu$ is thought to be the main decay mode for a heavy charged Higgs boson [$m_{H^+} > m_t + m_b$]
- Significant BR($H^+ \rightarrow Wh$) for:
  - 2HDM(2 Higgs Doublets) scenarios in which the 125GeV Higgs boson is the heaviest CP-even scalar
  - N2HDM(2 Higgs Doublets + Singlet) [arxiv:1910.06858]
  - Georgi-Machacek model (Higgs Triplet model) [https://journals.aps.org/prd/abstract/10.1103/PhysRevD.101.015029]

N2HDM:

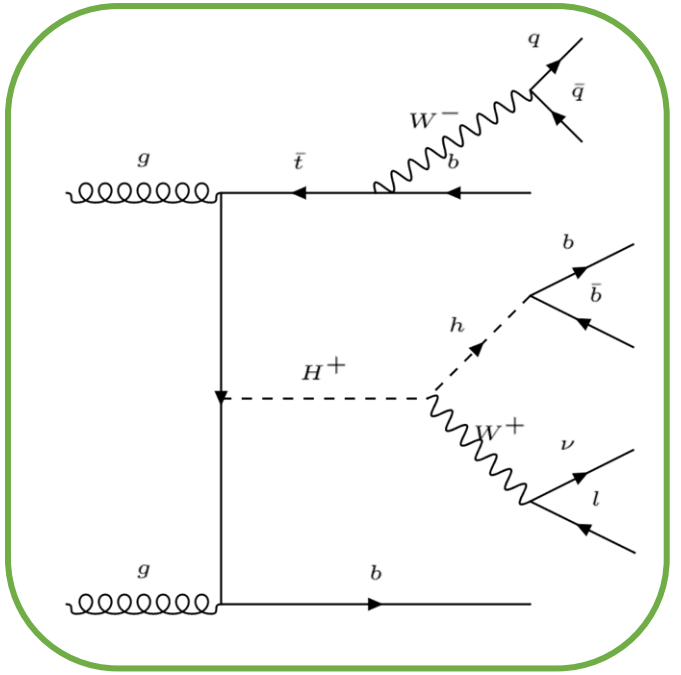


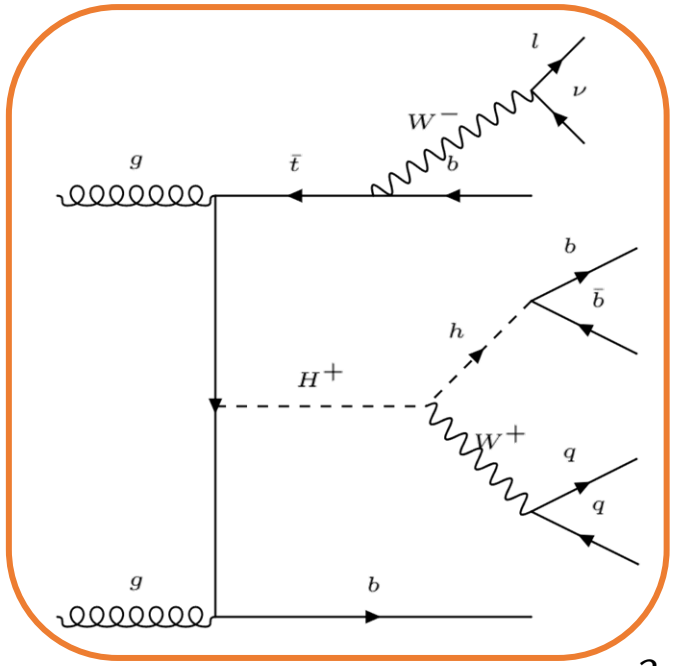
Georgi-Machacek model:



Signal Candidates

- Study H^+ produced in association with t and b and decay via $H^+ \rightarrow Wh$
  - Consider only events with one lepton
  - Multiple jets (>=6, 4 of them b tagged) in the final state
  - Missing transverse energy
  - $H^+ \rightarrow l\nu\ bb$: This talk
  - H^+ reconstruced from: 2 jets (h) and lepton and neutrino (W)
  - $H^+ \rightarrow qq\ bb$: T 62.2 by Shubham Bansal
  - H^+ reconstructed from: 4 jets (h)
- Challenges:
  - Find the combination of final state products corresponding to the H^+ decay
  - Decided which reconstruction approach to use



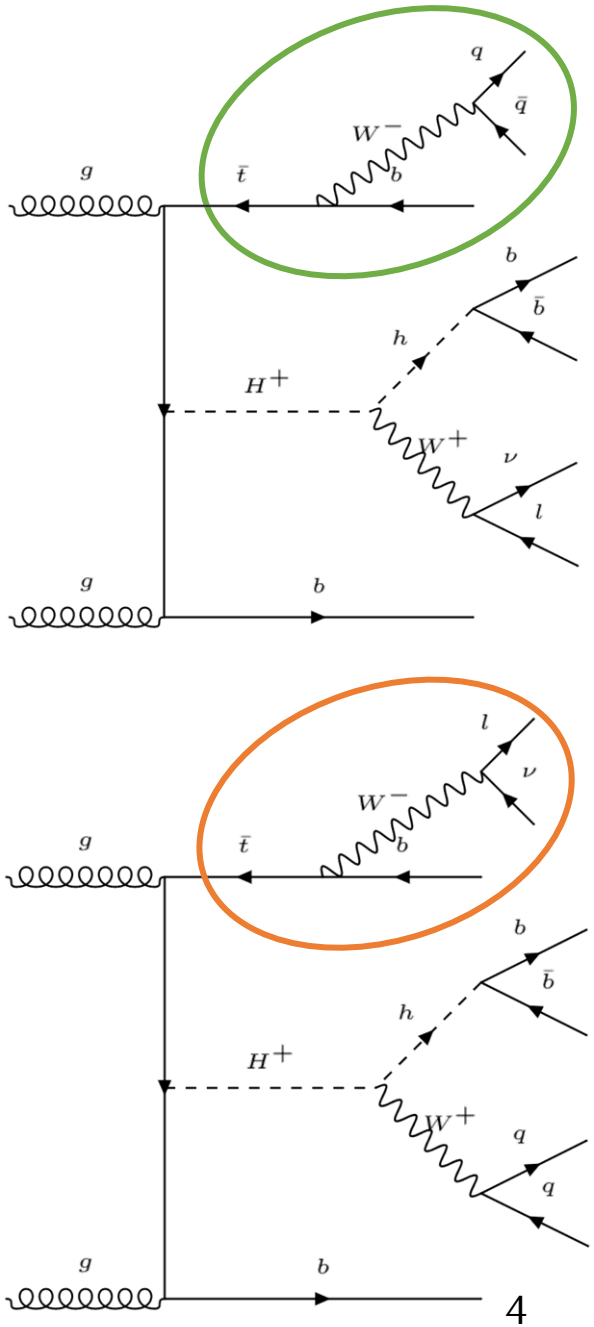


Classification of signal candidates : top reconstruction

- A method to distinguish $H^+ \to qqbb$ and $H^+ \to l\nu bb$ decays is needed
- Reconstruct a leptonically decaying top ($t \to l\nu b$) from:
  - probe all lvb combinations
  - Choose the combination that minimizes:

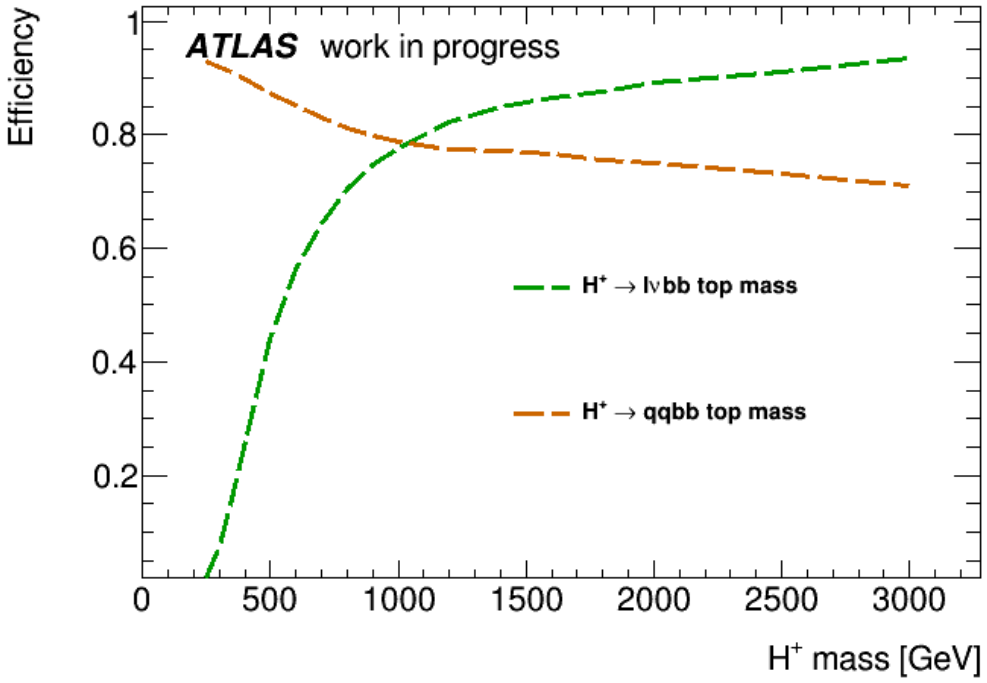
$$\frac{|m(W^{lep}+b) - m(t)|}{0.15 \times m(W^{lep}+b)}$$

- Classify events according to reconstructed top mass
  - m(lvb) < 225 GeV : $H^+ \to qqbb$
  - m(lvb) > 225 GeV : $H^+ \to l\nu bb$

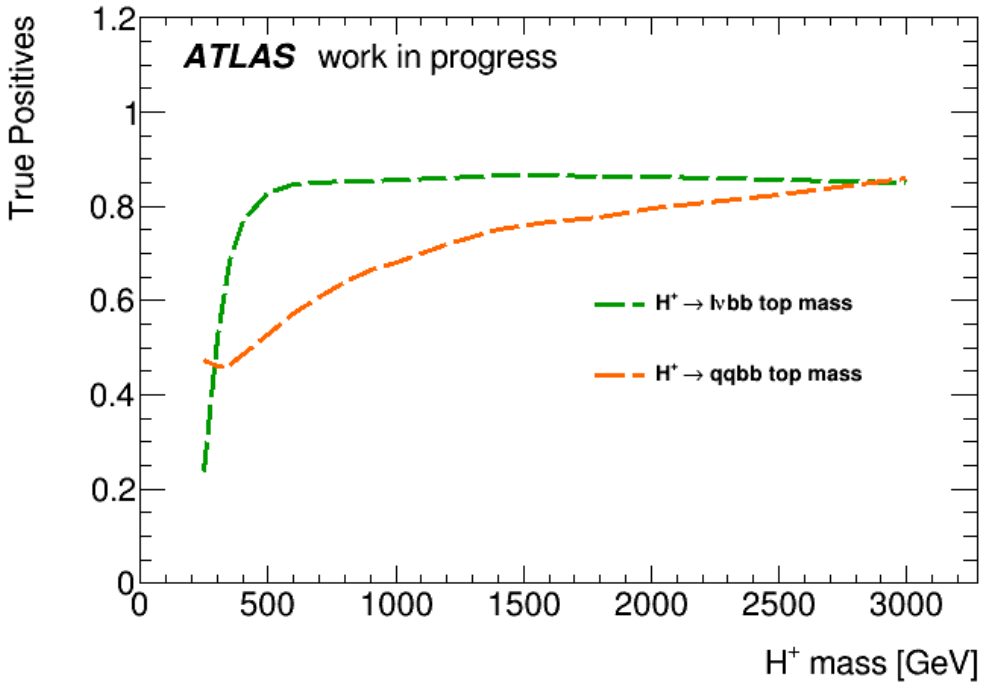


Signal classification performance

Identification efficiency: $\frac{\text{Events classified lvbb/qqbb}}{\text{Events that are lvbb/qqbb}}$



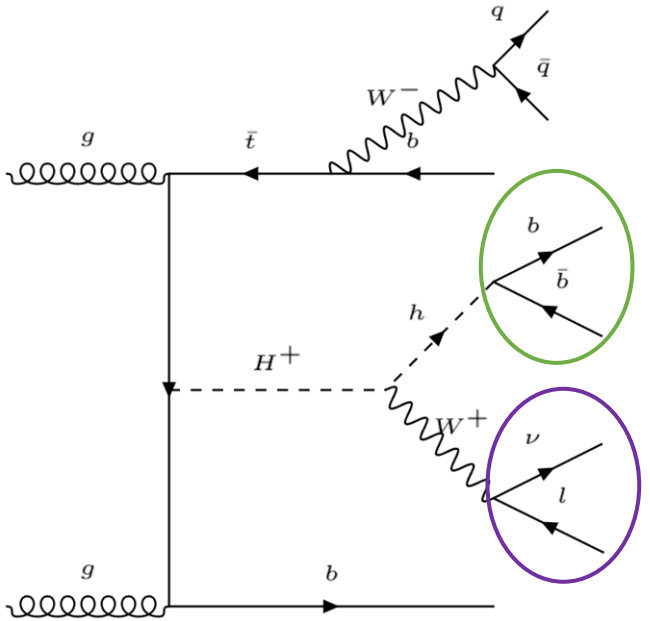
True positives: $\frac{\text{Events classified as lvbb/qqbb that are lvbb/qqbb}}{\text{Events classified as lvbb/qqbb}}$

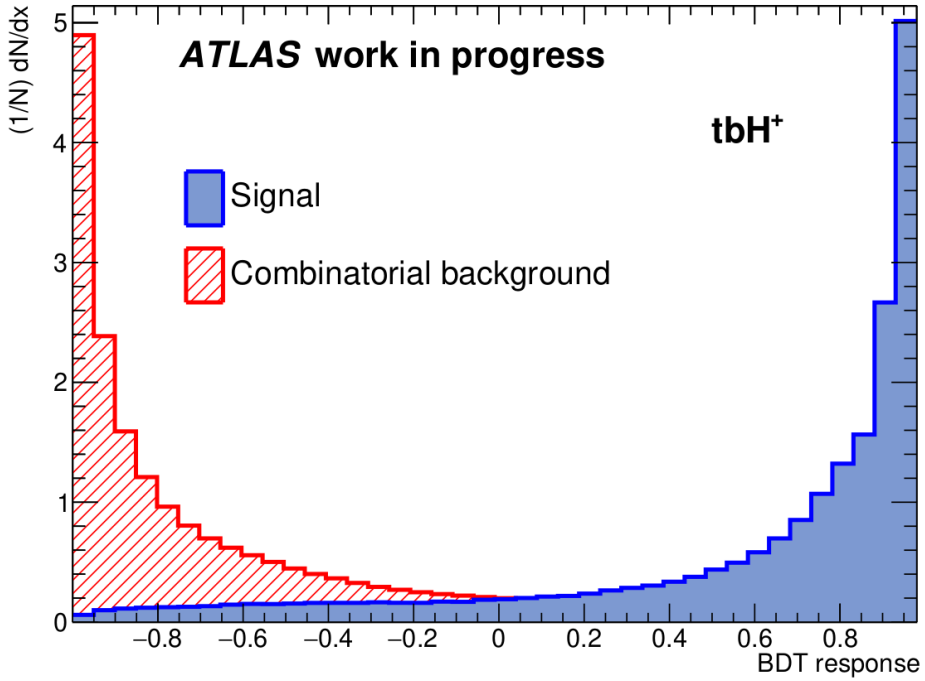


- Low identification efficiency for $H^+ \rightarrow$ lvbb at low masses

H^+ signal reconstruction

- Challenge: reconstruct $H^+ \rightarrow$ lvbb decay
- Reconstruct W from lepton and E_T^{miss}
- Reconstruct h from 2 jets
- Use boosted decision trees (BDTs) to choose the correct combination of a W boson with two jets from the h decay
- Signal: correct jet pair and lepton neutrino matched to H^+
- Combinatorial background: all the wrong combination
- Trained on sample containing several H^+ mass points
  - 250-3000 GeV
- Input variables for the training :
  - Higgs boson mass, b-tagging information of Higgs jets, $\Delta\Phi(j, W)$ p_T^h/m_{hW}, P_T^W/m_{hW}, $\Delta\eta(h, W)$

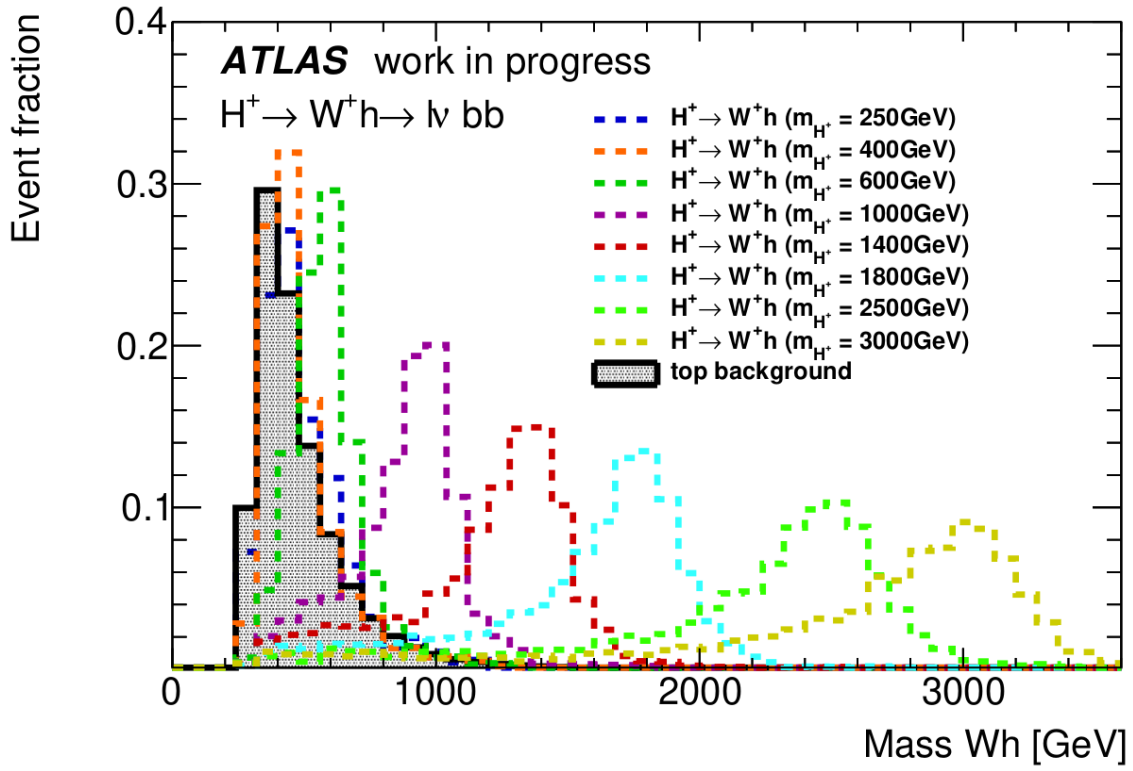




H^+ signal reconstruction: BDT application

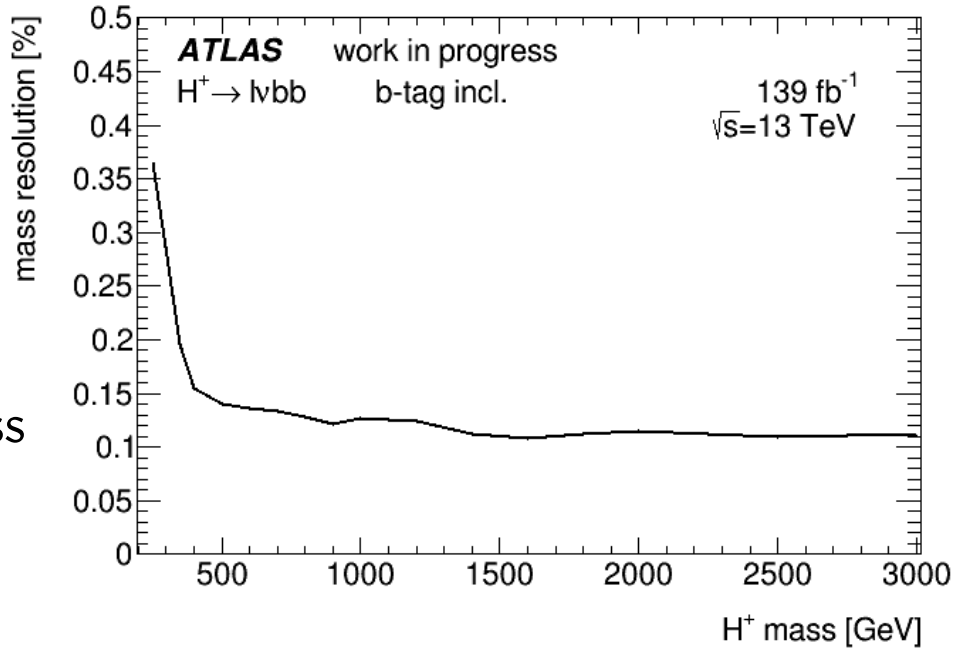
- Evaluate BDT for all possible lvjj combinations in the event
- Choose the $H^+ \rightarrow$ lvbb candidate with the highest BDT score (max BDT response) as H^+
- The BDT successfully reconstructs the H^+ decay

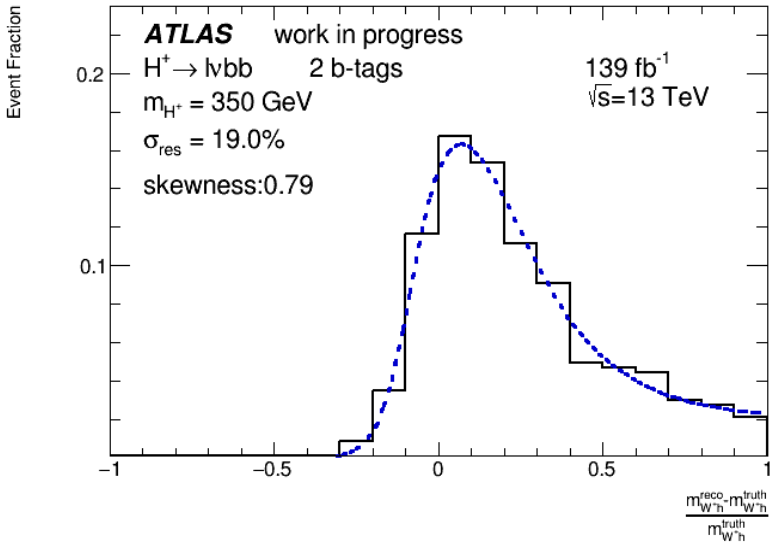
Reconstructed mass of lvbb events:

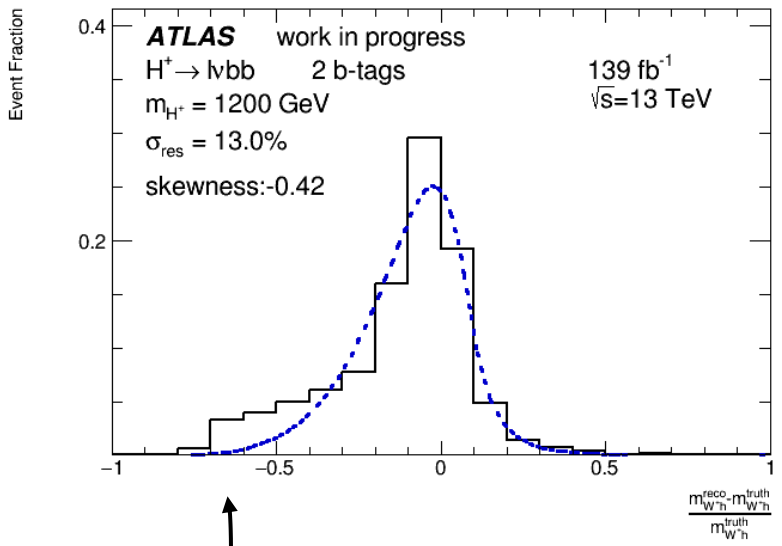


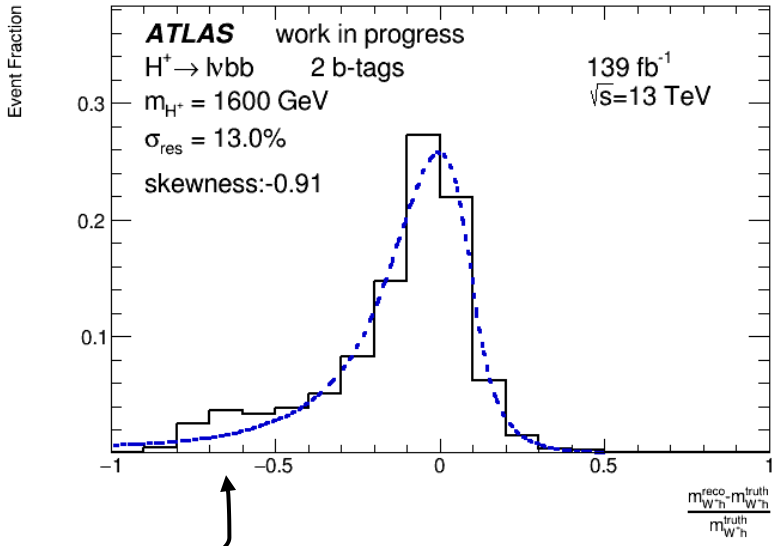
Signal mass resolution

- Considering only events passing the top mass requirement
- Calculate: $\frac{m_{W^+h}^{reco} - m_{W^+h}^{truth}}{m_{W^+h}^{truth}}$
- Fit asymmetric Bukin function to data and take the variance as the mass resolution
- Large tails stem from wrongly identified events





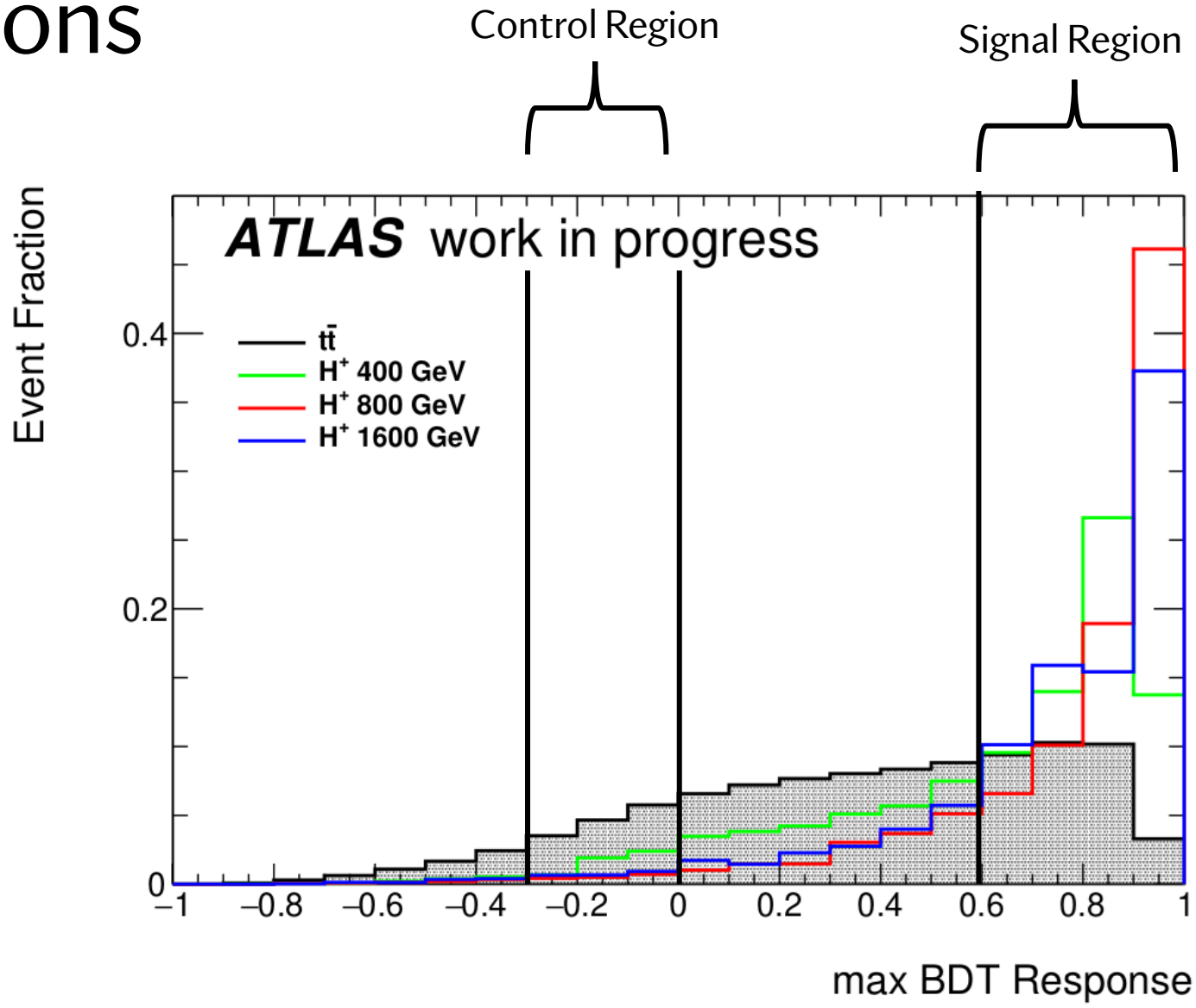




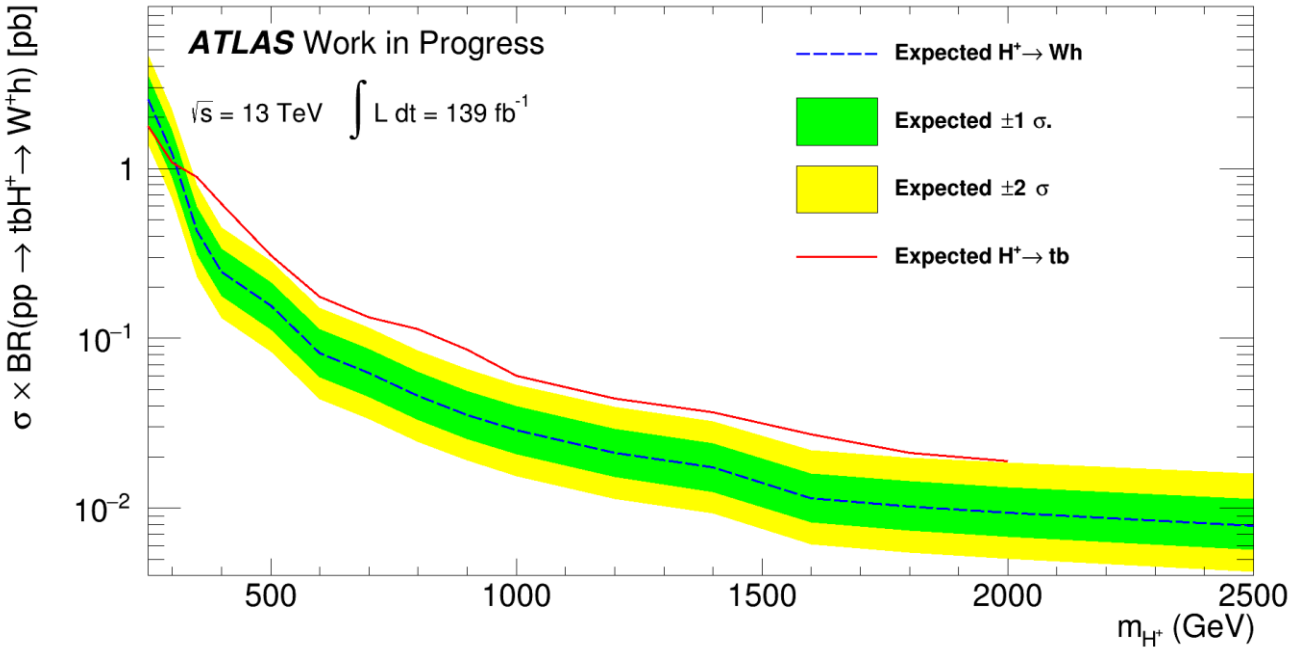
H⁺→qqbb events classified as lνbb

Signal and Control regions

- The maximal BDT Response is distinct between the signal and the background
- Define Signal and Control Region in terms of the maximal BDT Response
  - Optimize for maximal/minimal $\frac{s}{\sqrt{b}}$,while ensuring similar kinematic properties
- Signal Region: $w_{BDT}>0.6$
- Control Region: $-0.3>w_{BDT}>0.0$



Expected Limits on the tbH$^+$ cross section

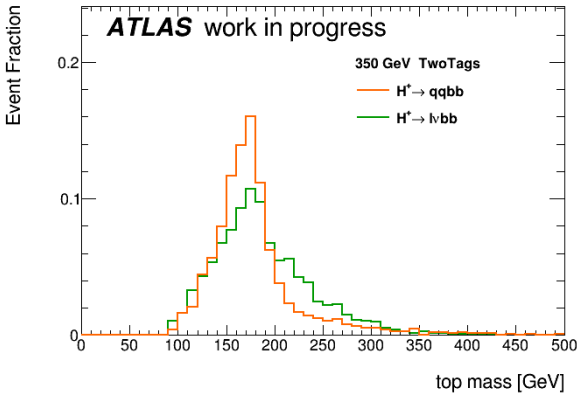


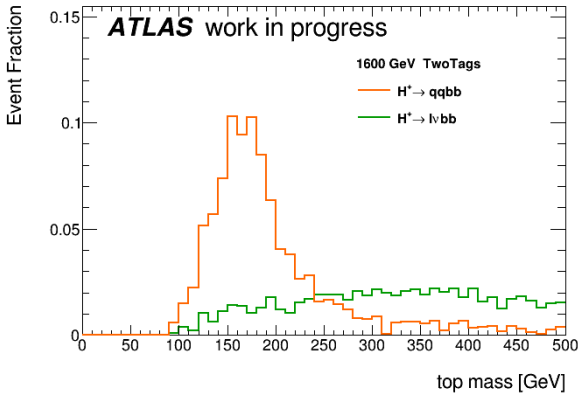
- Signal Region still blinded
- Perform the maximum likelihood fit of the expected signal and background m_{Wh} distribution
  - Simultaneous fit in 2 b-tag, 3 b-tag and 4+ b-tag region
- Only statistical uncertainties are taken into account
  - Statistical uncertainties (expected data stat. & MC stat.)
  - Luminosity uncertainties
  - Background normalisation
  - $t\bar{t}$ normalisation is freely floating
- Expected limits competitive with $H^+ \rightarrow tb$ [https://arxiv.org/abs/2102.10076v1.]
  - Both decay channels study similar final states
  - Background contributions are also similar

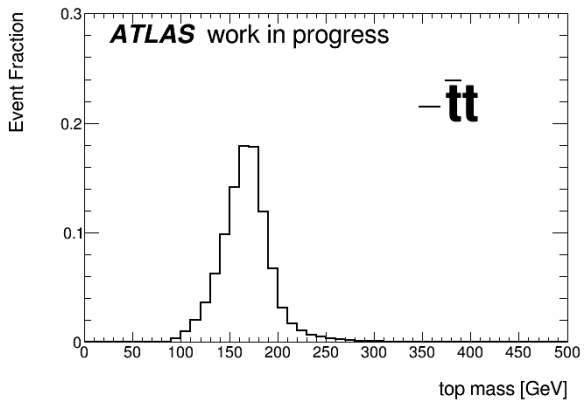
Summary/Next Steps

- $H^+ \rightarrow Wh$ studied for the first time at the LHC
  - Complementary to other H^+ searches e.g $H^+ \rightarrow tb$
- Signal reconstruction and classification for $H^+ \rightarrow$ lvbb was developed
  - The mass of a reconstructed t-quark is used to distinguish $H^+ \rightarrow$ lvbb and $H^+ \rightarrow$ qqbb decays
  - Boosted decision trees are sucesfully used to reconstruct the $H^+ \rightarrow$ lvbb decay
  - This BDT is furthermore used to define signal and control regions
  - Limits competitive with existing H^+ searches
- Next Steps:
  - Take systematic uncertainties into account systematics and perform preliminary fits
  - Perform data/MC comparisons in the control region

Back up


ATLAS work in progress
350 GeV TwoTags
H+→ qqbb
H+→ lνbb
Event Fraction
top mass [GeV]


ATLAS work in progress
1600 GeV TwoTags
H+→ qqbb
H+→ lνbb
Event Fraction
top mass [GeV]


ATLAS work in progress
$t\bar{t}$
Event Fraction
top mass [GeV]