A search for charged Higgs bosons at the LHC with the ATLAS detector

Blake Burghgrave

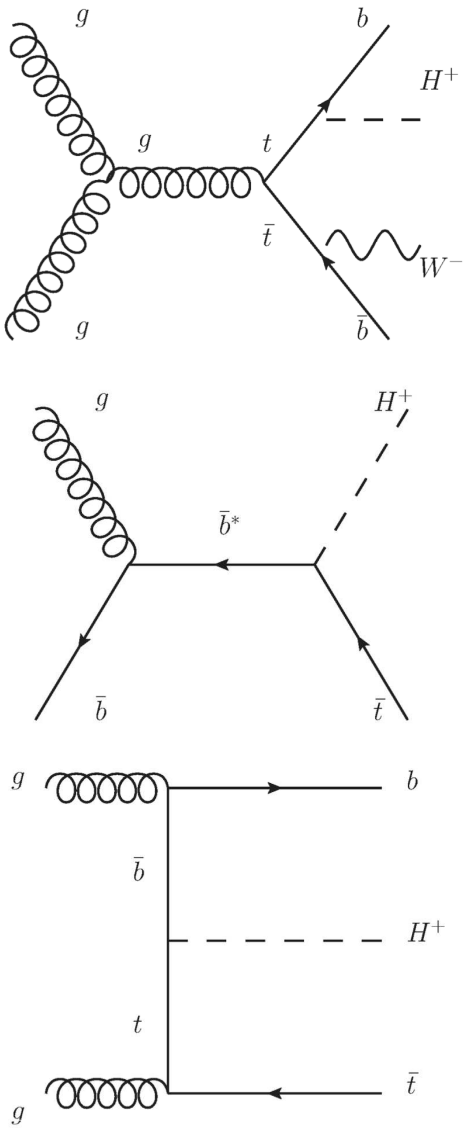
Northern Illinois University

APS DIVISION OF PARTICLES & FIELDS

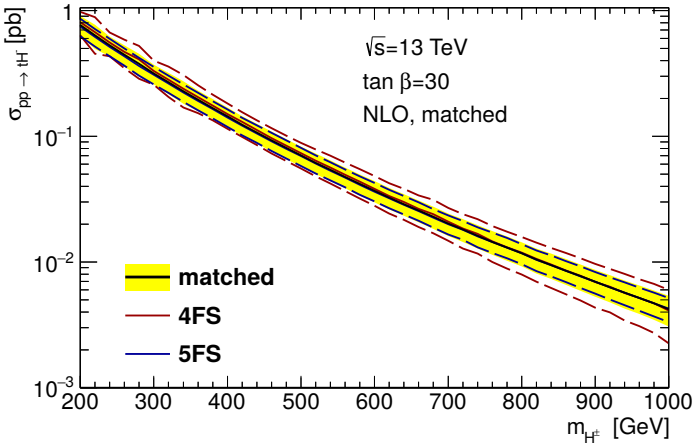
DPF 2017

Overview

- $H^{\pm}$ are expected in association with a top quark
  - Low-mass: $t\bar{t}$ decays
  - High-mass: Like Wt, with W replaced by $H^{\pm}$
- This talk considers $H^{\pm} \to \tau\nu$
  - τ decays hadronically
  - Hadronic top quark decay $\to$ τ+jets final state
  - Leptonic top quark decay $\to$ τ+lep final state
- Work-in-progress, mostly from τ+lep
- Structure of this talk:
  - Theory and Motivation
  - Comparison to latest ATLAS results (ICHEP)
  - Background modeling
  - Analysis strategy
  - Expected limits

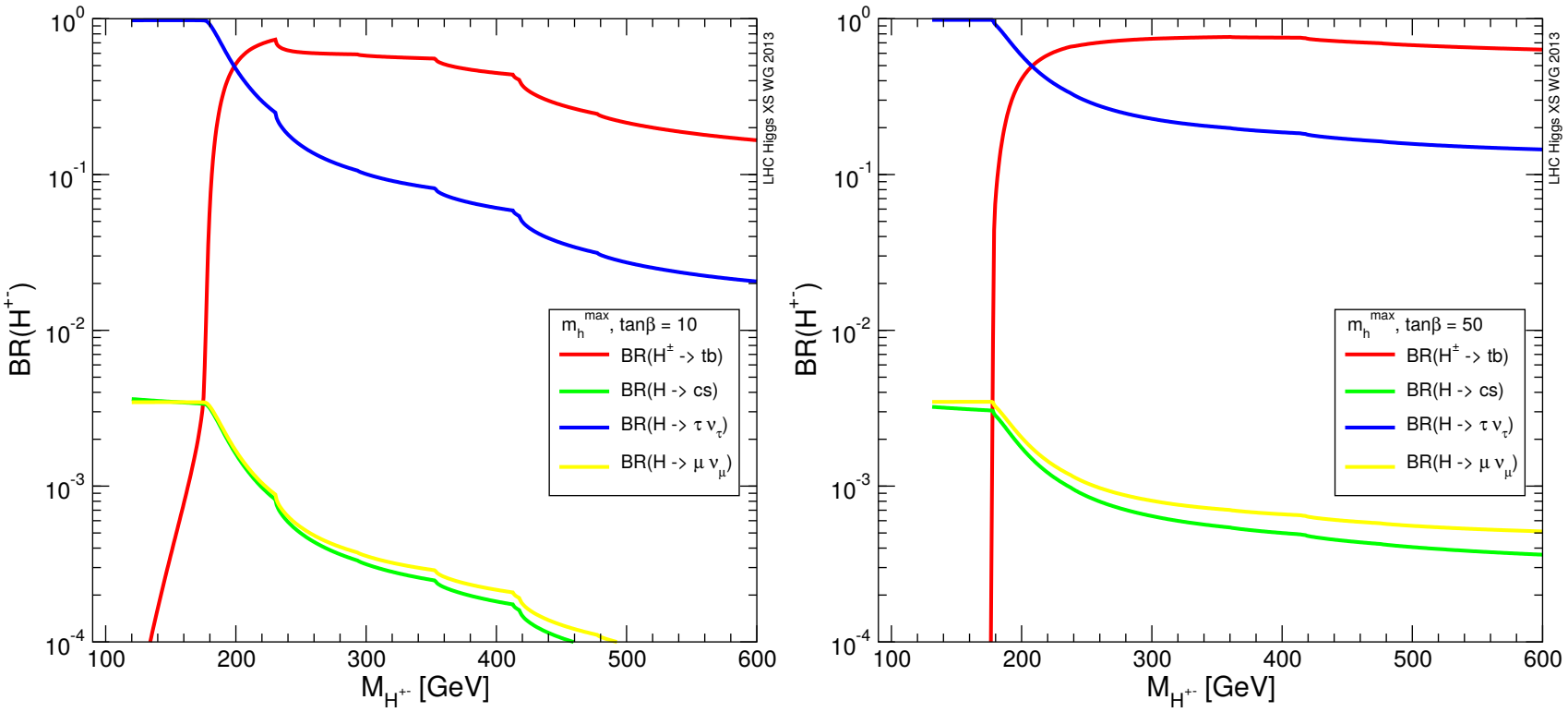


(arXiv:1409.5615)



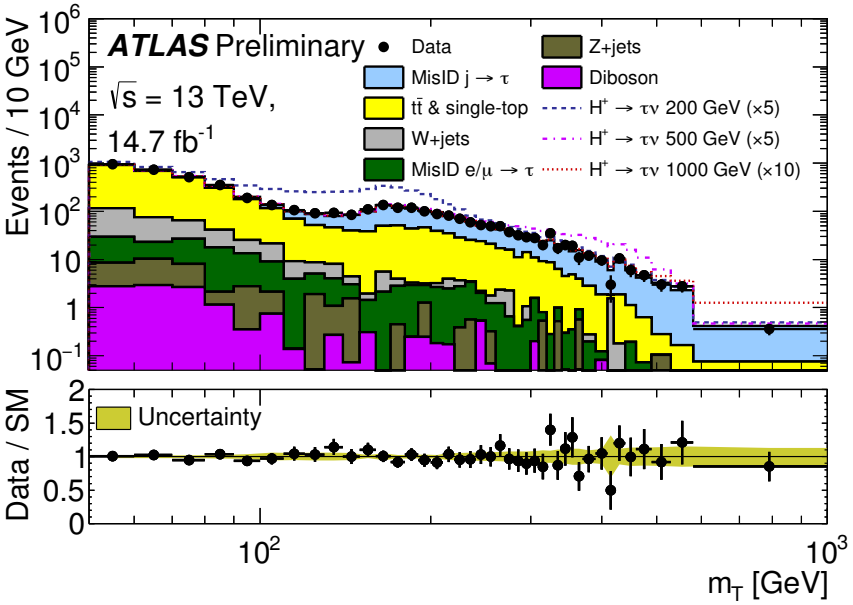
Motivation

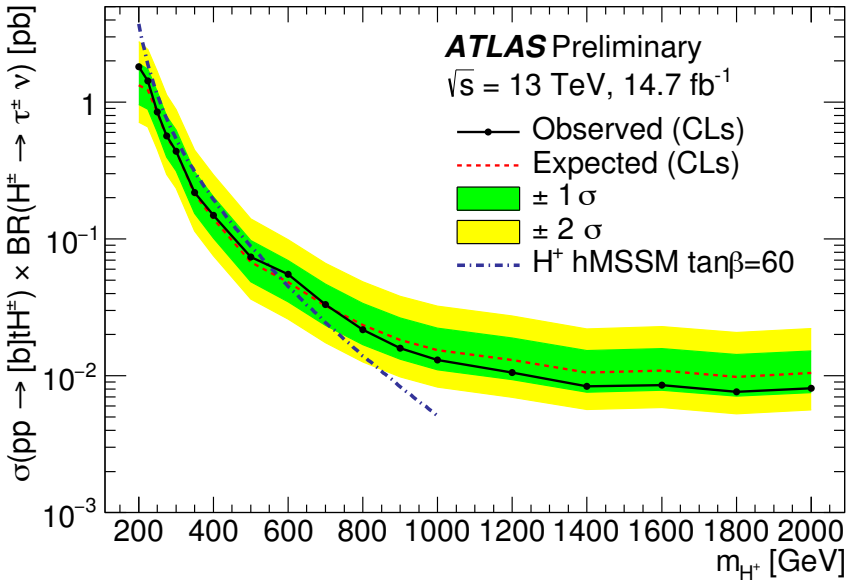
- Extensions to the Higgs sector include additional Higgs Bosons
- In particular, a Type II (MSSM-like) 2 Higgs Doublet Model includes:
  - Two neutral scalars h and H
  - One neutral pseudoscalar A
  - Charged H^+ and H^-
- $H^\pm$ decay modes depend on the particles' mass and the ratio of the VEVs of the doublets ($\tan\beta$)
- $H^\pm \to \tau\nu$ (blue curve) looks promising, and is the topic of this talk



(arXiv:1307.1347)

Changes since ICHEP

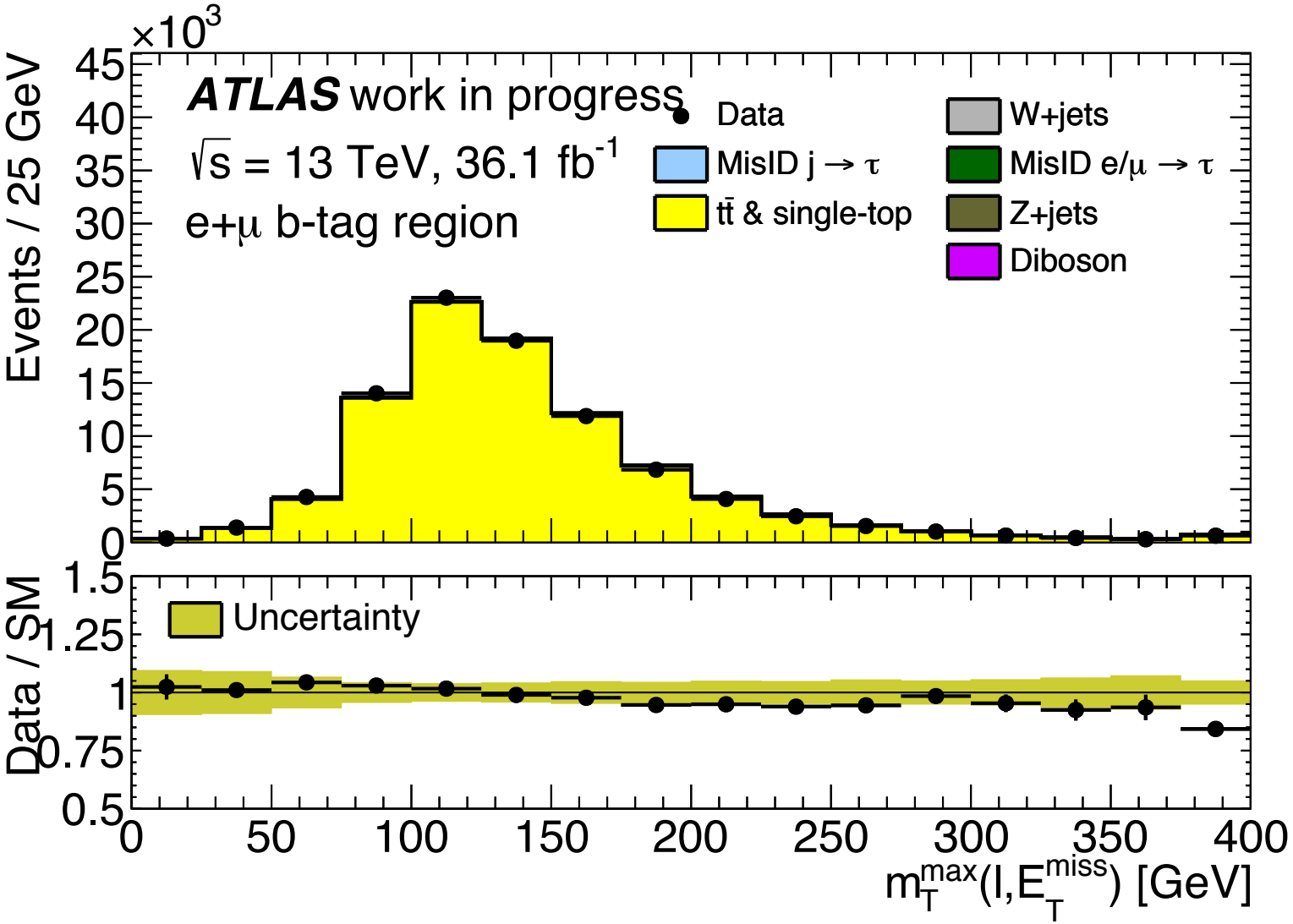




(ATLAS-CONF-2016-088)

- Some changes since the last ATLAS $H^{\pm} \to \tau\nu$ result (ICHEP, above)
  - Added τ+lep channel
  - Systematics and background normalization constrained with $t\bar{t}$ and W+jets CRs
  - Low-mass $H^{\pm}$ added, 90 – 160 GeV, last included in Run 1
  - Intermediate-mass $H^{\pm}$ added, 160–180 GeV, never included before
  - Multi-Variate Analysis used, formerly $m_{\mathrm{T}}(\tau, E_{\mathrm{T}}^{\mathrm{miss}})$

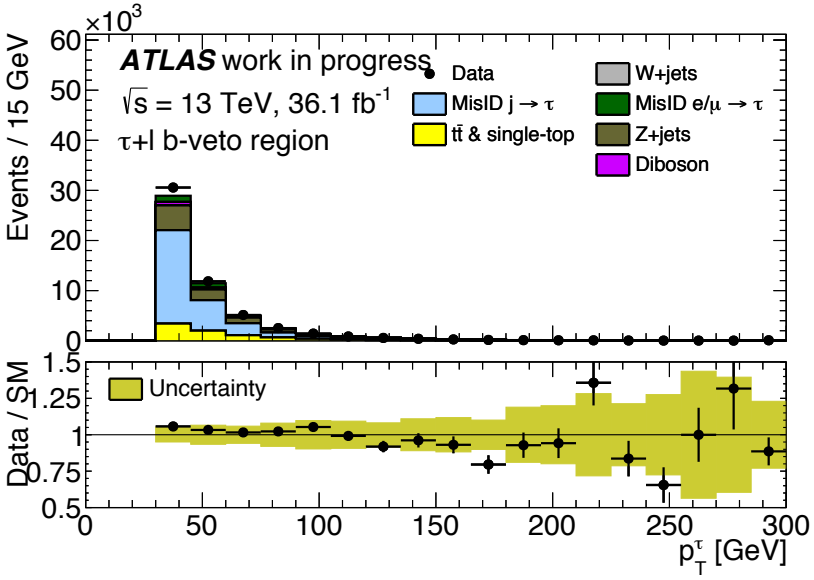
$t\bar{t}$ Background

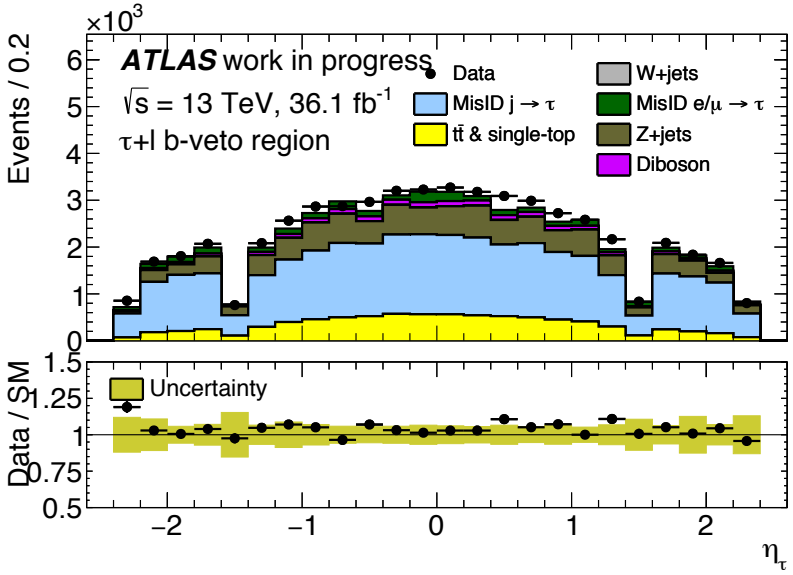


- Dominant SM background is top quark production
- A dilepton region, almost pure $t\bar{t}$, is used to constrain systematics
- Same selection as τ+lep SR, but replace τ with an $e + \mu$ selection

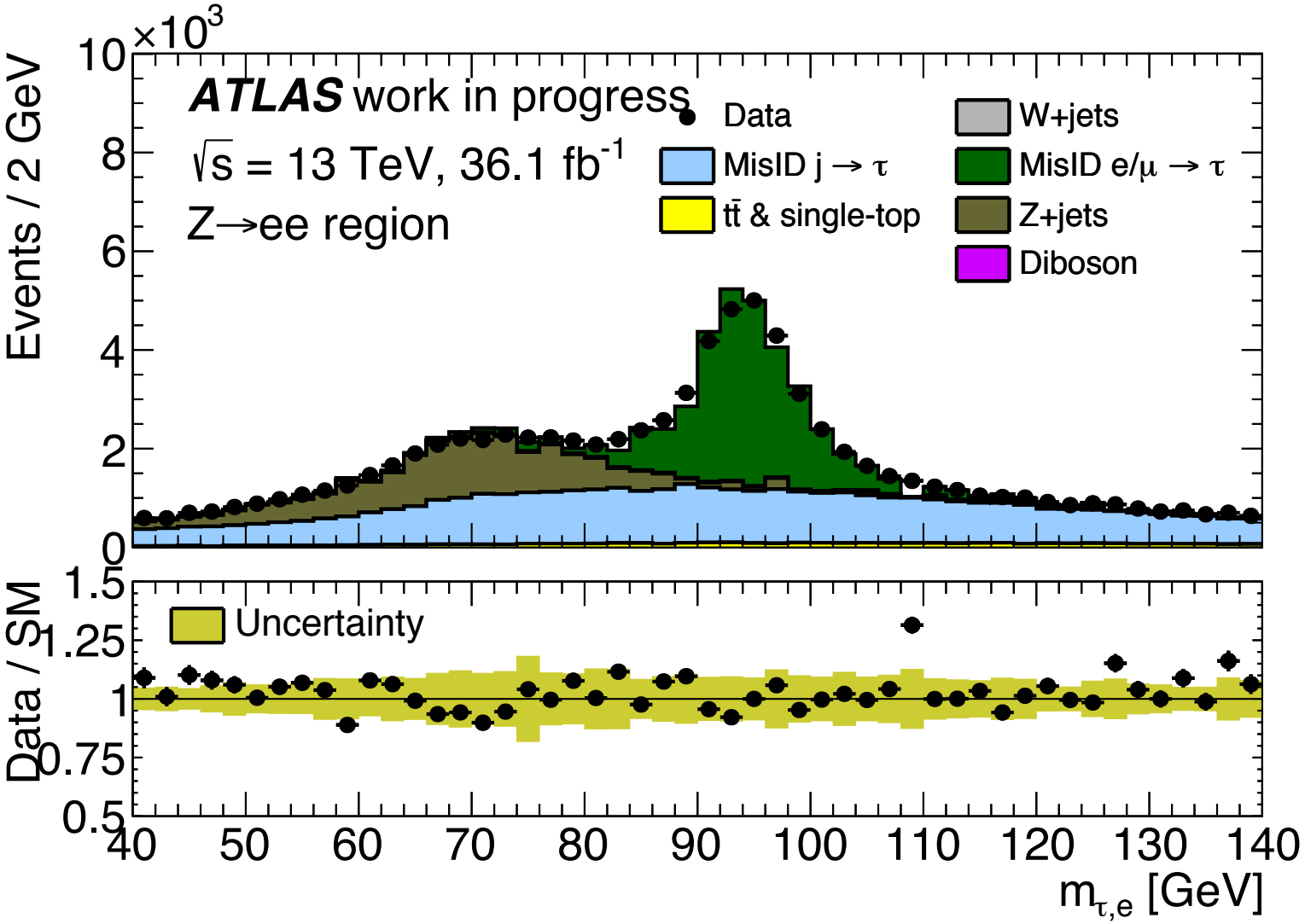
jet $\rightarrow \tau$ Fakes

- jet $\rightarrow \tau$ are a significant background
- Modeled with a data-driven fake-factor method
  - FF measured in CRs with fakes from Multi-Jet (QCD) and W+jets events
  - Define anti-τ as objects failing τ-ID but passing a looser ID
  - FF$= \frac{N_{\text{fake-}\tau}}{N_{\text{anti-}\tau}}$, binned in p_{T}^{τ} and N_{tracks}^{τ}
  - Using FF: $N_{\text{fake-}\tau} = \text{FF} \times N_{\text{anti-}\tau}$
- rQCD approach is used to apply FFs in SRs and CRs
  - Weighted average of FFs from QCD/W+jets CRs
  - Relative weights from template fit on τ-ID BDT scores of anti-τ





$\ell \to \tau$ Fakes



- $\ell \to \tau$ fakes are a small background in the SR
- Checked in a $Z \to ee$ region, found to be modeled well by MC

Analysis Strategy

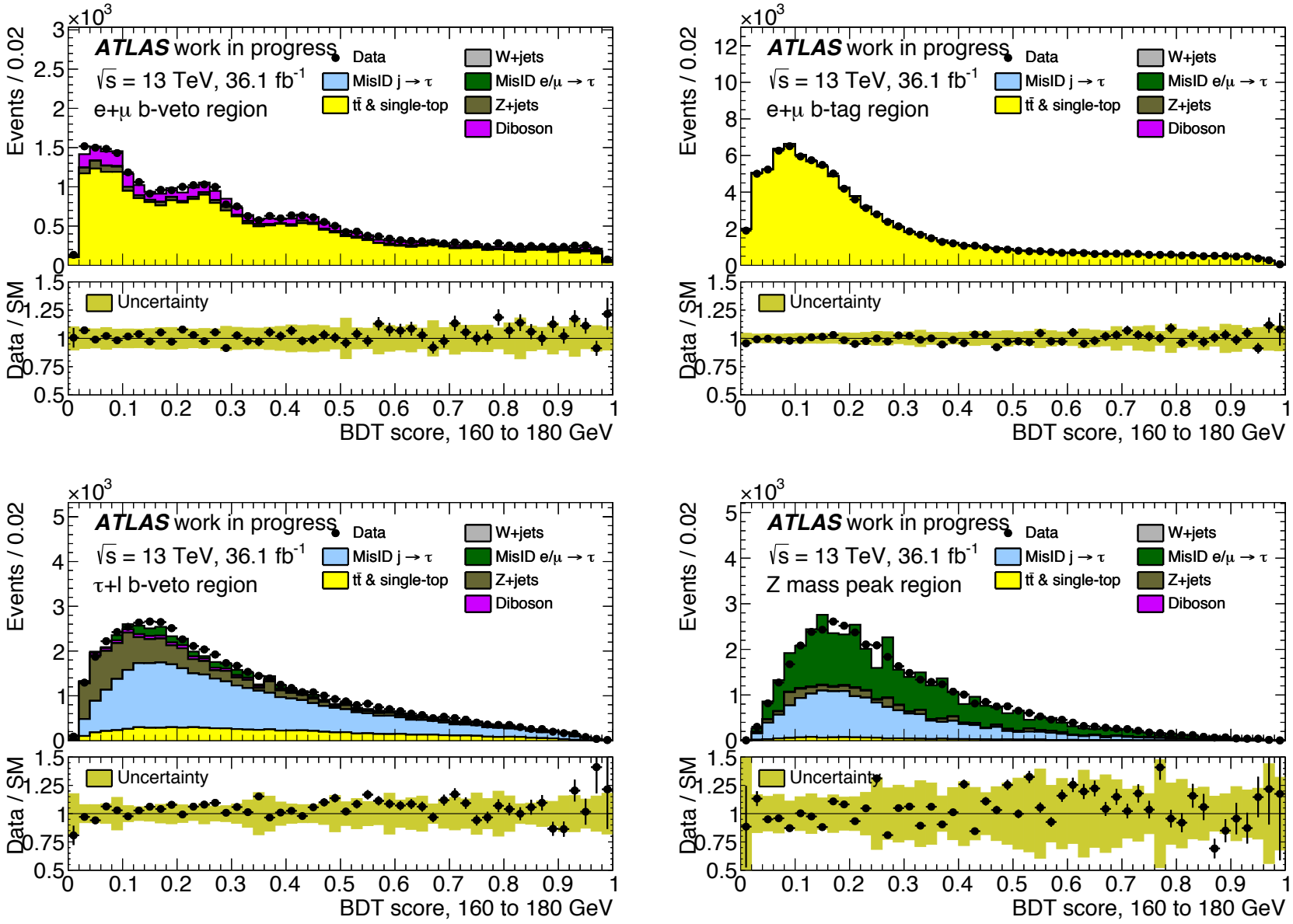
- Multi-Variate Analysis using Boosted Decision Trees
  - FastBDT trained via a TMVA plugin
  - Signal binned in 5 mass ranges:
    - 90 to 120 GeV
    - 130 to 160 GeV (low mass 160 GeV)
    - 160 to 180 GeV (intermediate mass)
    - 200 to 400 GeV
    - 500 to 2000 GeV
  - Trained against dominant $t\bar{t}$ background
  - Data-driven jet$\rightarrow \tau$ fakes included in 500 to 2000 GeV for τ+jets
  - Background modeling and BDT training kept statistically independent via the k-fold method

MVA input variable	τ+jets	τ+lep
$E_{\mathrm{T}}^{\mathrm{miss}}$	✓	✓
p_{T}^{τ}	✓	✓
$p_{\mathrm{T}}^{b\text{-jet}}$	✓	✓
p_{T}^{ℓ}		✓
$\Delta\phi_{\tau,\mathrm{miss}}$	✓	✓
$\Delta\phi_{b\text{-jet},\mathrm{miss}}$	✓	✓
$\Delta\phi_{\ell,\mathrm{miss}}$		✓
$\Delta R_{\tau,\ell}$		✓
$\Delta R_{b\text{-jet},\ell}$		✓
$\Delta R_{b\text{-jet},\tau}$	✓	
$\Upsilon = 2\frac{p_{\mathrm{T}}^{\tau\text{-track}}}{p_{\mathrm{T}}^{\tau}} - 1$	✓	✓

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Background
Partition 1	Evaluation	Train	Train	Train	Train	Fold 1
Partition 2	Train	Evaluation	Train	Train	Train	Fold 2
Partition 3	Train	Train	Evaluation	Train	Train	Fold 3
Partition 4	Train	Train	Train	Evaluation	Train	Fold 4
Partition 5	Train	Train	Train	Train	Evaluation	Fold 5

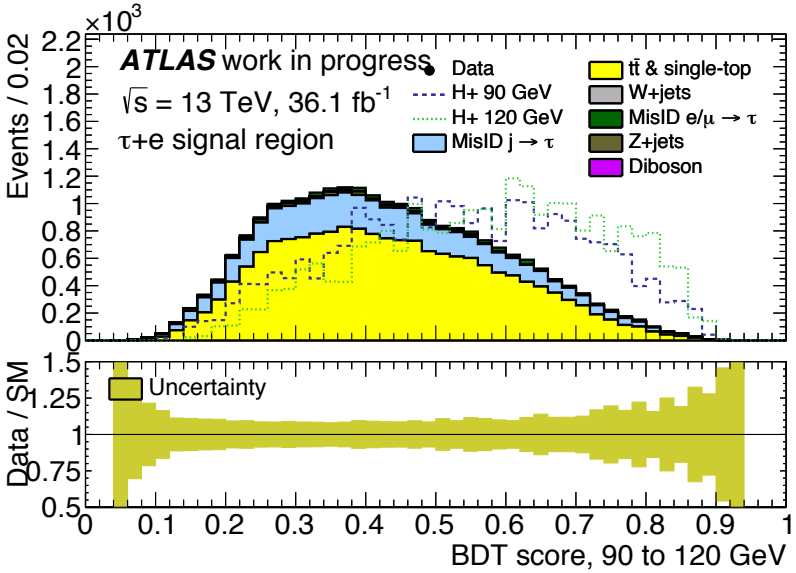
- BDT score used as discrminating variable, fit with profile likelihood ratio
- Fitted regions: τ+jets, $\tau + e$, $\tau + \mu$, and CRs for $t\bar{t}$ and W+jets

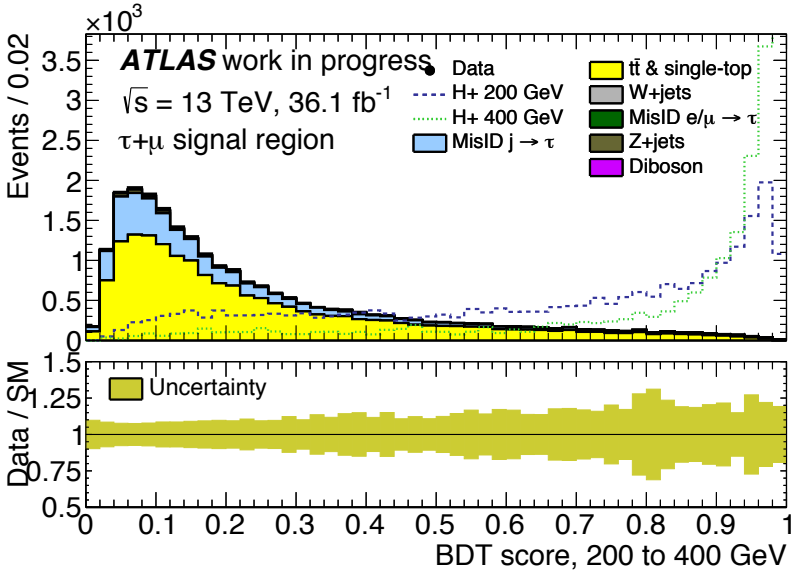
BDT Distributions in Validation/Control Regions



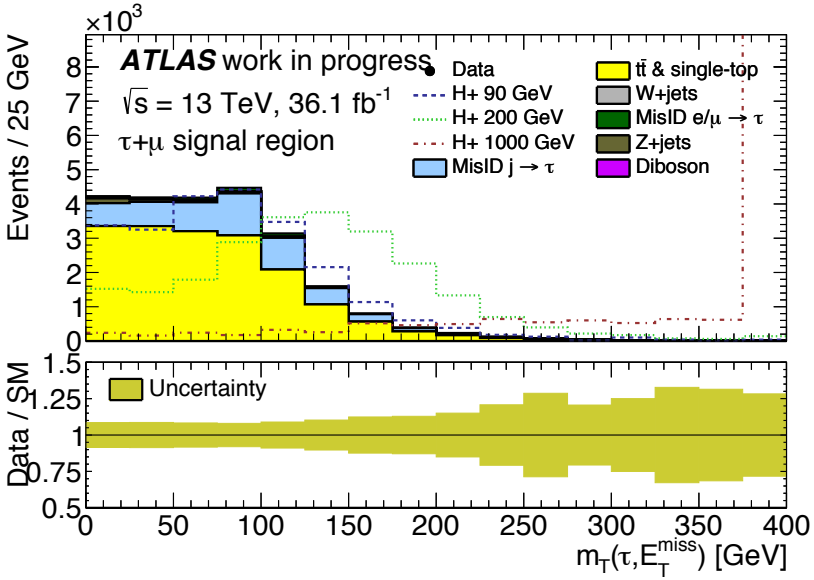
- BDT scores in τ+lep validation regions
- Agreement between data/background looks good

Expected BDT Distributions in Signal Regions

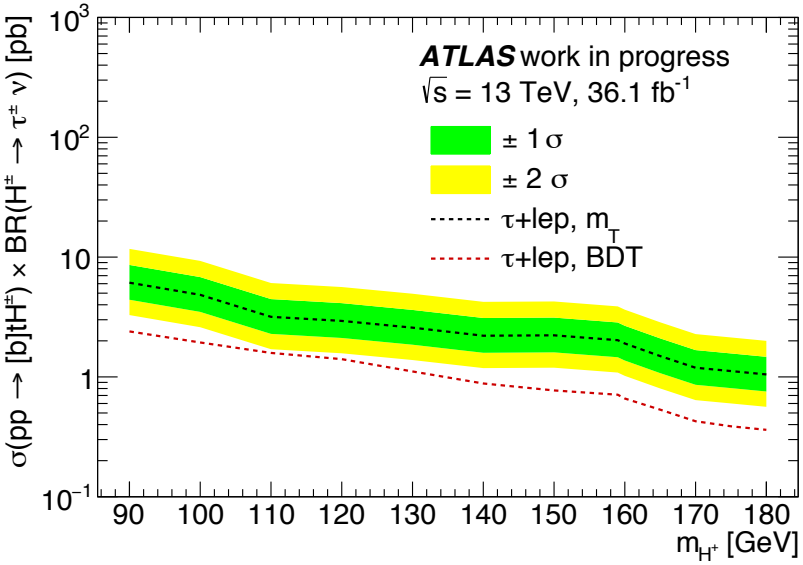


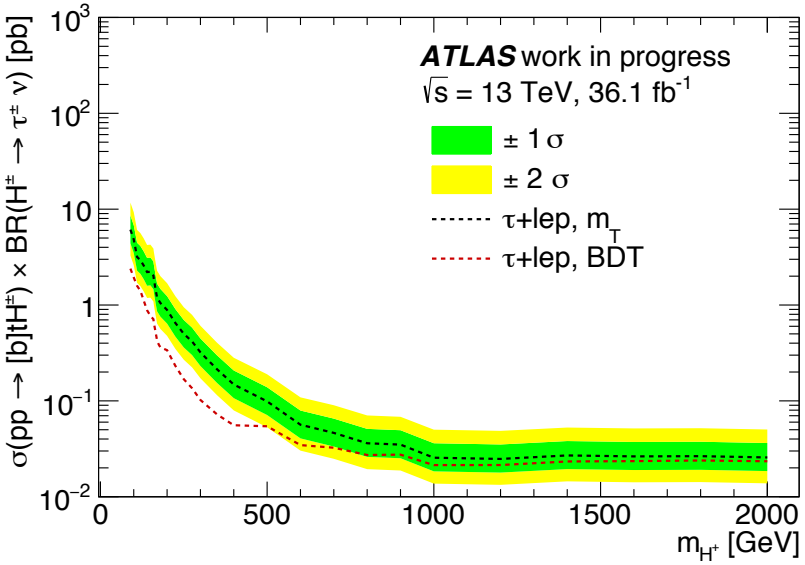


- τ+lep BDT score distributions (above) compared to $m_{\mathrm{T}}(\tau, E_{\mathrm{T}}^{\mathrm{miss}})$ (right)
- Signal normalized to background
- Significant improvement visible at 90 GeV (dark blue) and 200 GeV (dark blue in the top right, green in the bottom right)



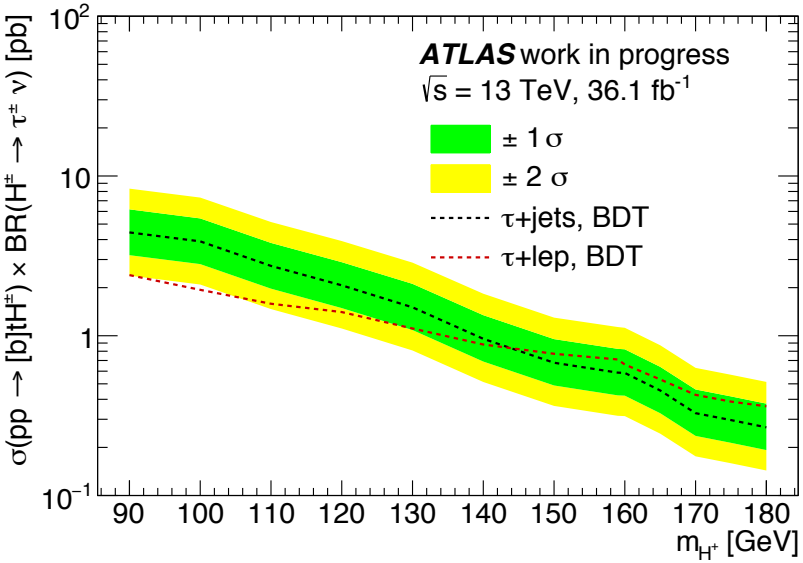
Expected Limits, BDT vs m_T

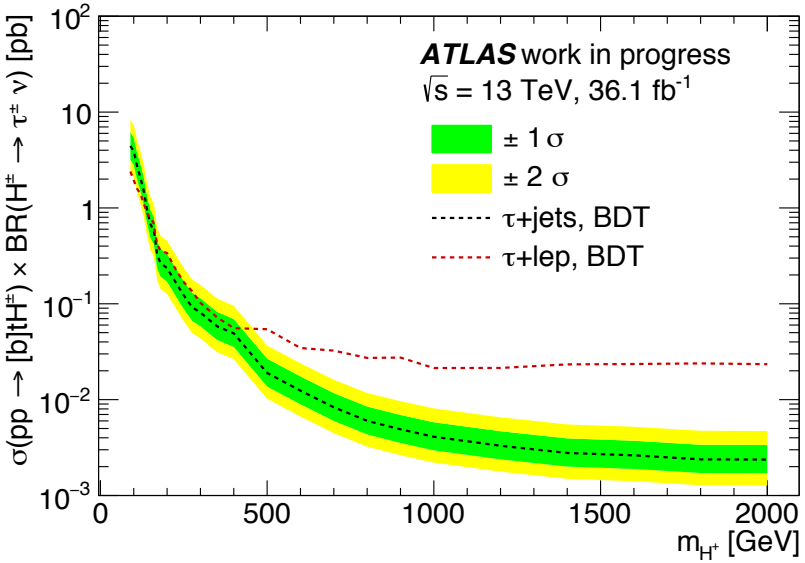




- Comparison of limits (w/o systematics) for cut-based and MVA approach
- MVA gives improvement over the full mass range, largest at lower masses

Expected Limits, τ+lep and τ+jets





- Comparison of limits (w/o systematics) for τ+lep and τ+jets
- τ+lep more sensitive at low-mass
- τ+jets more sensitive at high-mass
- Comparable performance below ~400 GeV, expect improvements with combined limit

Conclusion

- Many improvements to the search for $H^{\pm} \to \tau\nu$
- Signal mass range extended to low mass, now 90 to 2000 GeV
- First look at the intermediate mass range (near the top quark mass)
- Multi-Variate Analysis improves sensitivity
- Good data/background agreement in our CRs
- Including CRs in fit will constrain systematics