Search for charged Higgs Bosons in $H^{+} \rightarrow Wh$ decays

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LHC Seminar

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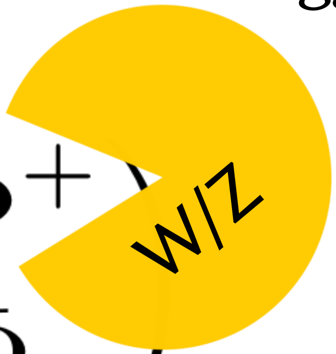
Introduction

- In the SM, the Higgs sector has been chosen to be as simple as possible
- Several extensions of the SM predict an extended Higgs sector
  - e.g Supersymmetry
- OR extended Higgs model can solve many of the open questions in physics
  - Dark Matter
  - Strong CP problem
  - Neutrino masses
  - Baryon asymmetries
- Models with additional Higgs doublets or triplets predict electrically charged scalars H+

$$\Phi_{SM} = \begin{pmatrix} \Phi^+ \\ \Phi_0 \end{pmatrix}$$

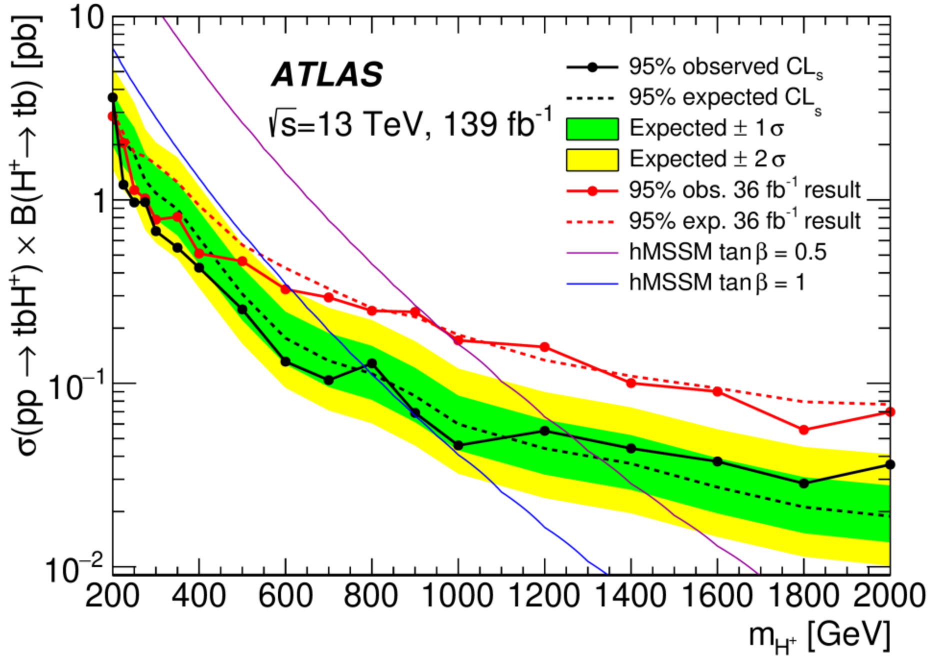


$$\Phi_{BSM} = \begin{pmatrix} \Phi^+ \\ \Phi_0 \end{pmatrix}$$

Manifest themselves as charged particles

Previous Charged Higgs boson searches

- Lep searches
  - $e^+ e^- \rightarrow y/Z \rightarrow H^+ H^-$
  - Relative model independent
  - Limit $m(H^+) > 80$ GeV
- LHC searches have focused on decay modes
  - $H^+ \rightarrow tb$ (Interesting for high masses)
  - $H^+ \rightarrow$ tau v (Interesting for high/low masses)
  - $H^+ \rightarrow cs$ (Interesting for high/low masses)
- Indirect Searches
  - e.g Flavor observables,
  - Highly model dependent!
- So far uncovered at the LHC $H^+ \rightarrow Wh$ (h=125 GeV) !
  - Significant Branching ratios in several models:
  - Georgi-Machacek model
  - 2HDM outside the alignment limit
  - N2HDM
  - 3HDM

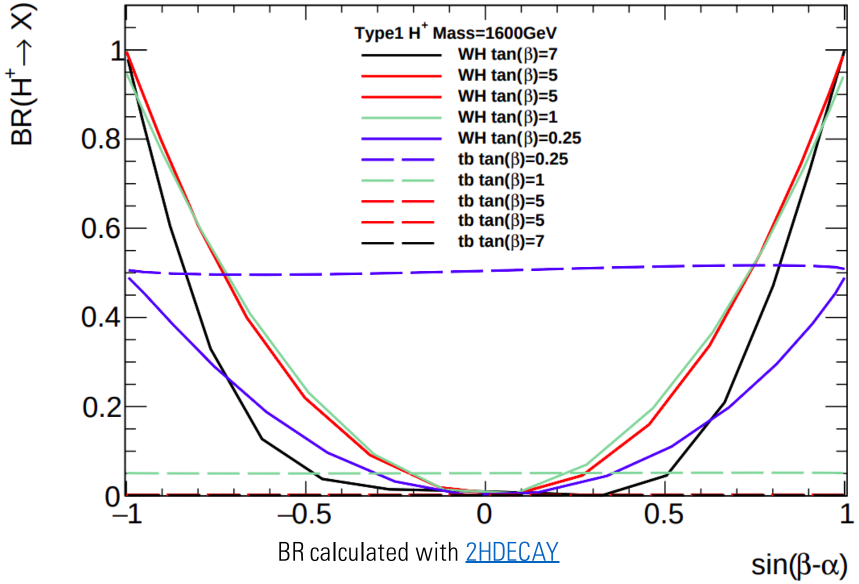


Mass limits for $m_{H+} > m(top)$

$m > 181$ GeV, CL = 95% $(\tan\beta = 10)$
$m > 249$ GeV, CL = 95% $(\tan\beta = 20)$
$m > 390$ GeV, CL = 95% $(\tan\beta = 30)$
$m > 894$ GeV, CL = 95% $(\tan\beta = 40)$
$m > 1017$ GeV, CL = 95% $(\tan\beta = 50)$
$m > 1103$ GeV, CL = 95% $(\tan\beta = 60)$

2HDM

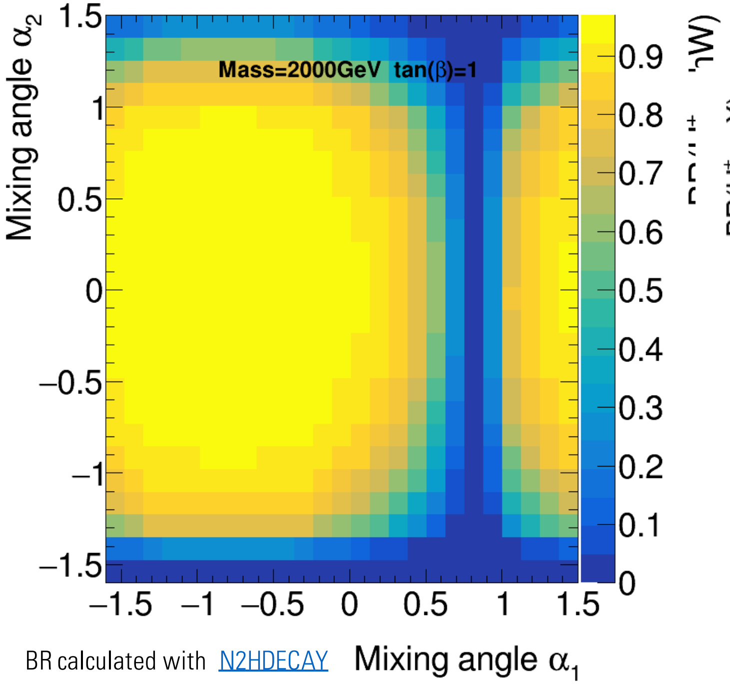
- 2 Higgs doublets
- Particles:
  - 2 CP-Even Higgs bosons h ,H
  - 1 Pseudoscalar A
  - 2 Charged Higgs bosons
- $\tan(\beta) = \left(\frac{v_1}{v_2}\right)$
- α mixing angle between h H
  - $\sin(\beta-\alpha)$->1(light Higgs boson SM-like)
  - $\sin(\beta-\alpha)$->0(heavy Higgs boson SM-like)



BR calculated with 2HDECAY

N2HDM

- 2 Higgs doublets + singlet
- Particles:
  - 3 CP-Even Higgs bosons
  - 1 Pseudoscalar A
  - 2 Charged Higgs bosons
- 3 Mixing angles: $\alpha_1, \alpha_2, \alpha_3$
- $\tan(\beta) = \left(\frac{v_1}{v_2}\right)$

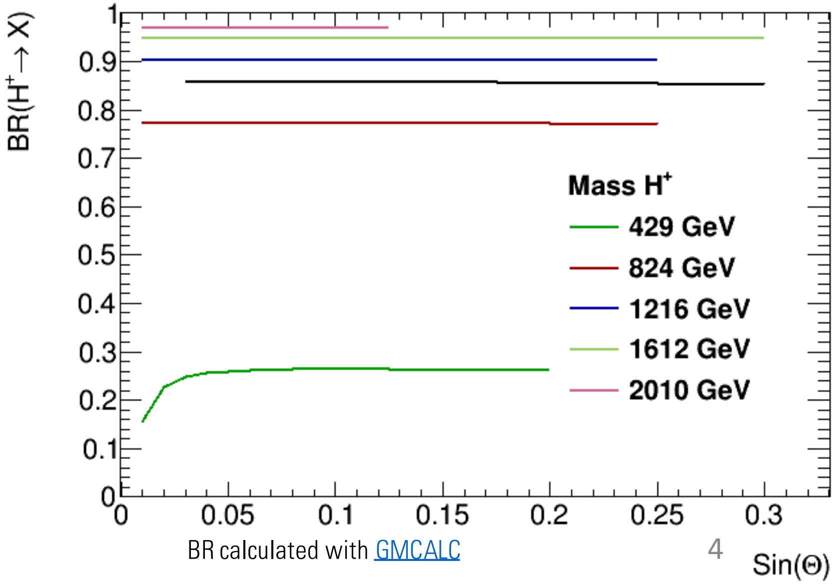


BR calculated with N2HDECAY

Georgi-Machacek

- Additional real and complex Higgs triplet
- Particles:
  - Fiveplet states:
    - $H_5^{++} \backslash H_5^{--}, H_5^{+} \backslash \mathrm{H}_5^{-}, H_5$
  - Triplet states:
    - $H_3^{+} \backslash \mathrm{H}_3^{-}, H_3$
  - Singlet states:
    - h, H

$$\sin\Theta = \frac{2\sqrt{2}v_\chi}{v} \qquad v_\chi = \text{VEV-Triplet} \qquad \text{v=SM-VEV}$$



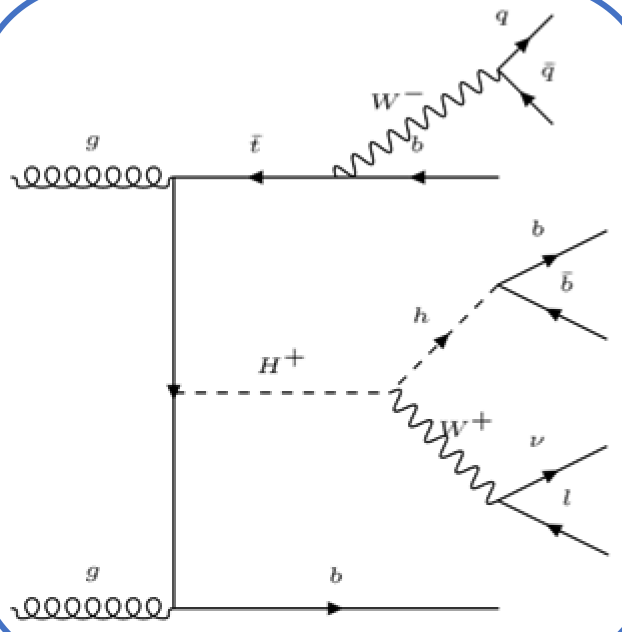
BR calculated with GMCALC

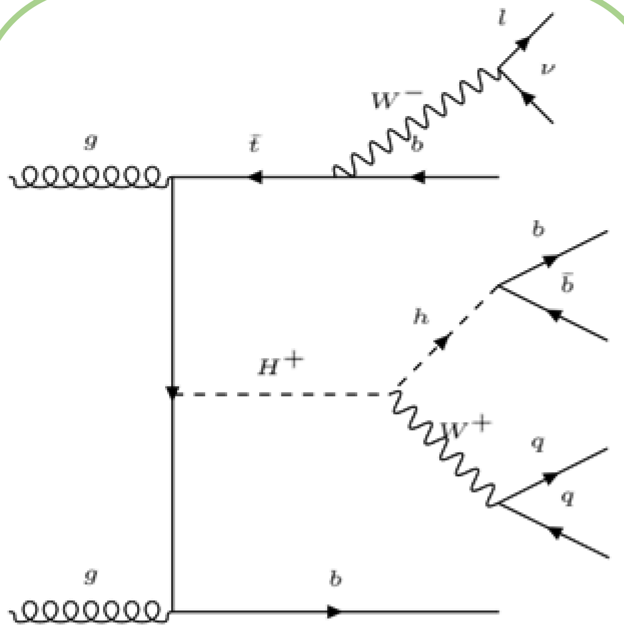
Analysis strategy

$H^{+} \to Wh$

Analysis Strategy

- H^+ is produced in association with t and b
- Target the lνqqbbbb final state
  - h→bb
  - W→lν
  - W→qq
- Reconstruct the H^+ mass and use a the discriminating variable against the background
- Challenge: reconstruct H^+ out of this complicated final H^+ :
  - 2 jets+ MET+lepton
  - 4 jets
- Use BDTs to solve jet combinatorics
- Challenge: distinguish between these two decay modes
  - Reconstruct the top quark



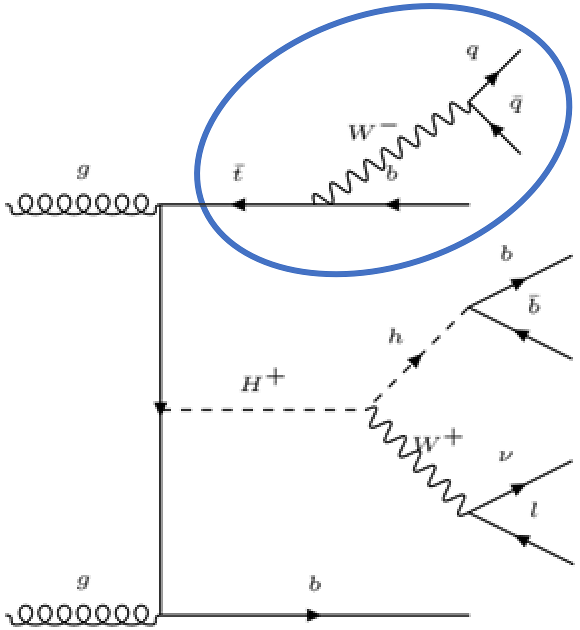


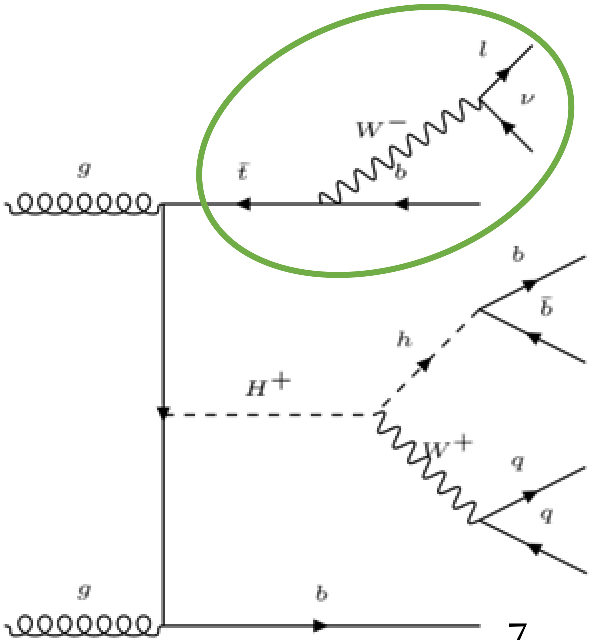
Classification of signal candidates : top reconstruction

- A method to distinguish $H^{+} \longrightarrow$ qqbb and $H^{+} \longrightarrow$ lνbb decays is needed
- Reconstruct a leptonically decaying top (t ⟶ lνb) :
  - probe all lνb combinations
  - Choose the combination that minimizes:

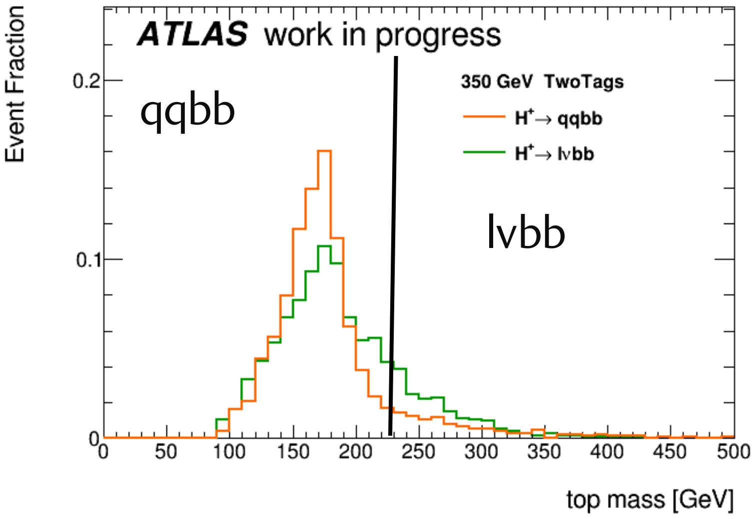
$$\frac{|m(W^{lep}+b)-m(t)|}{0.15\times m(W^{lep}+b)}$$

- Classify events according to reconstructed top mass
  - m(lνb) < 225 GeV : $H^{+} \longrightarrow$ qqbb
  - m(lνb) > 225 GeV : $H^{+} \longrightarrow$ lνbb

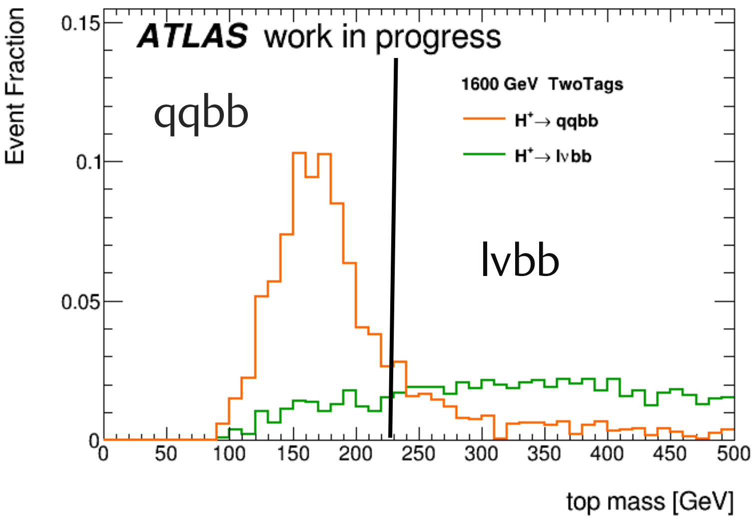




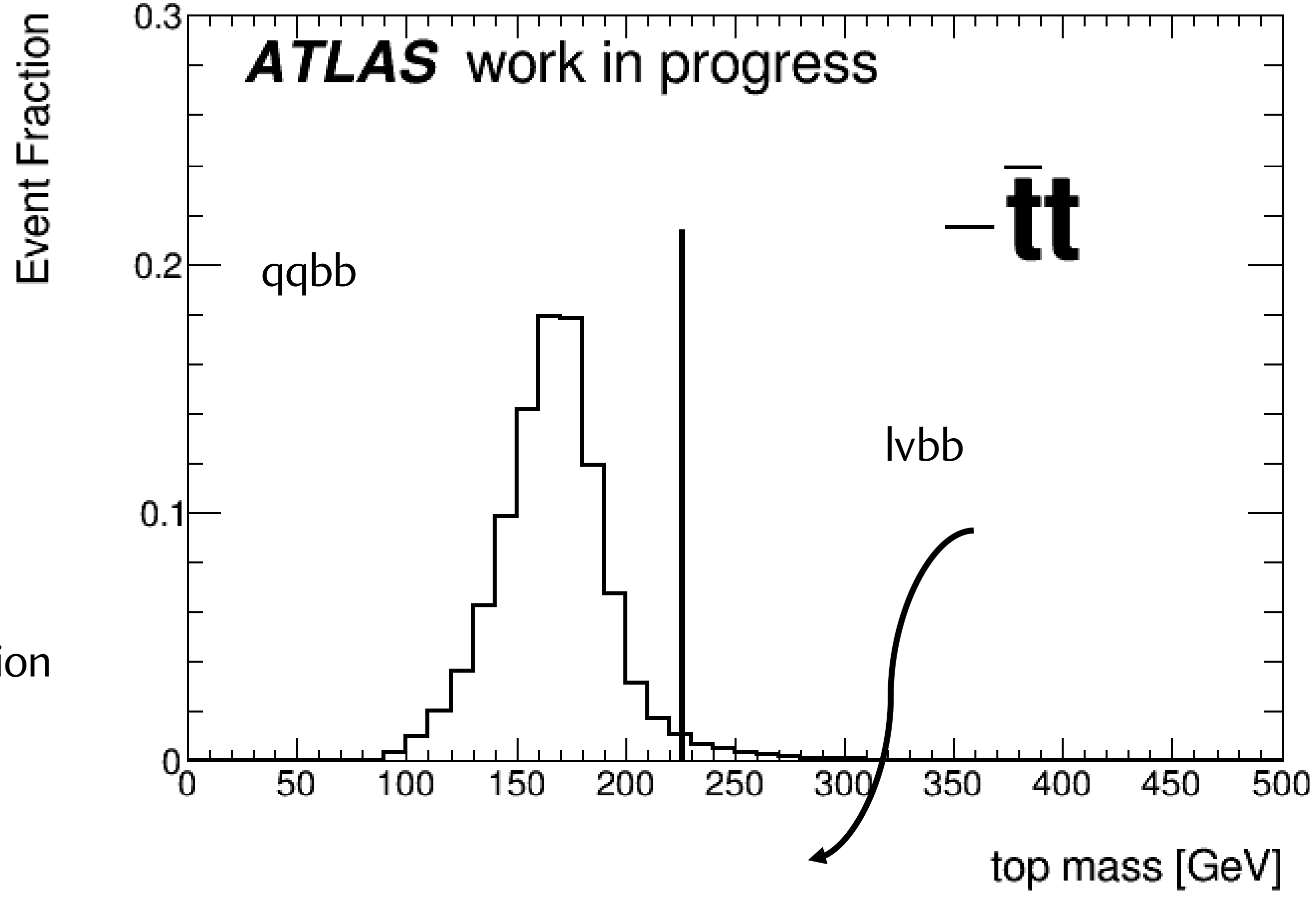
Signal classification performance



Only small separation for low H^+ masses

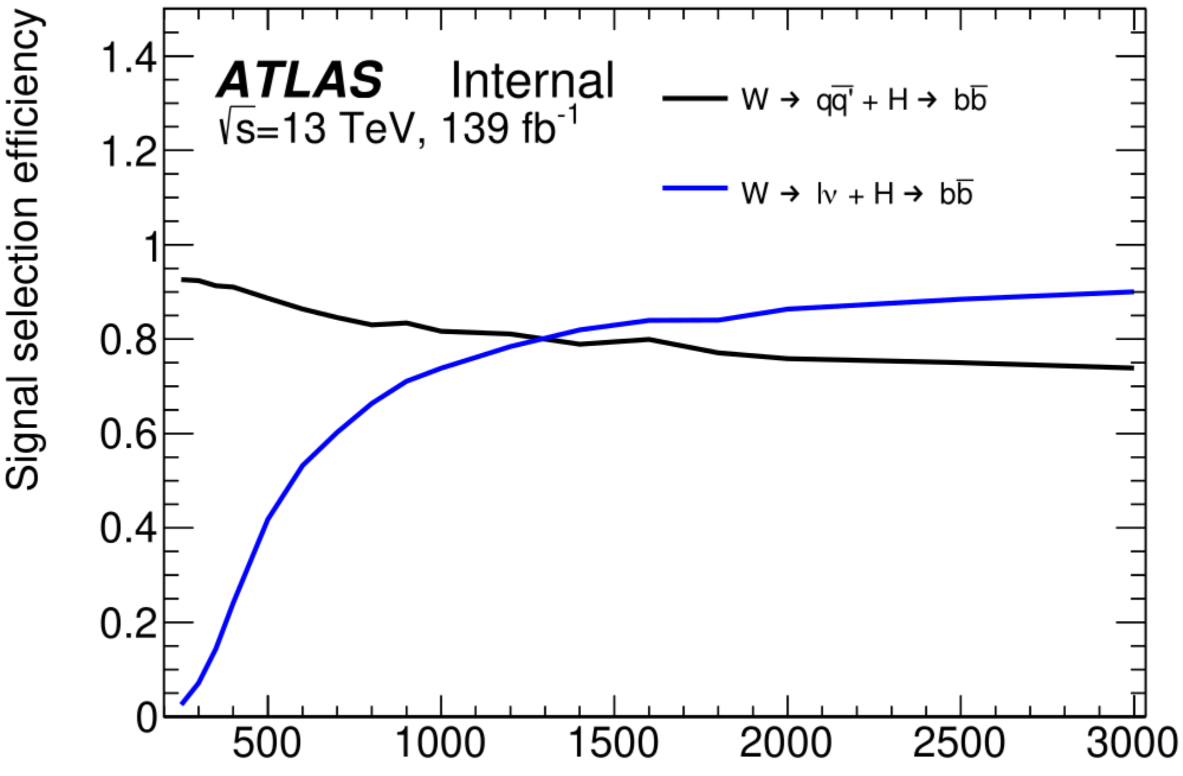


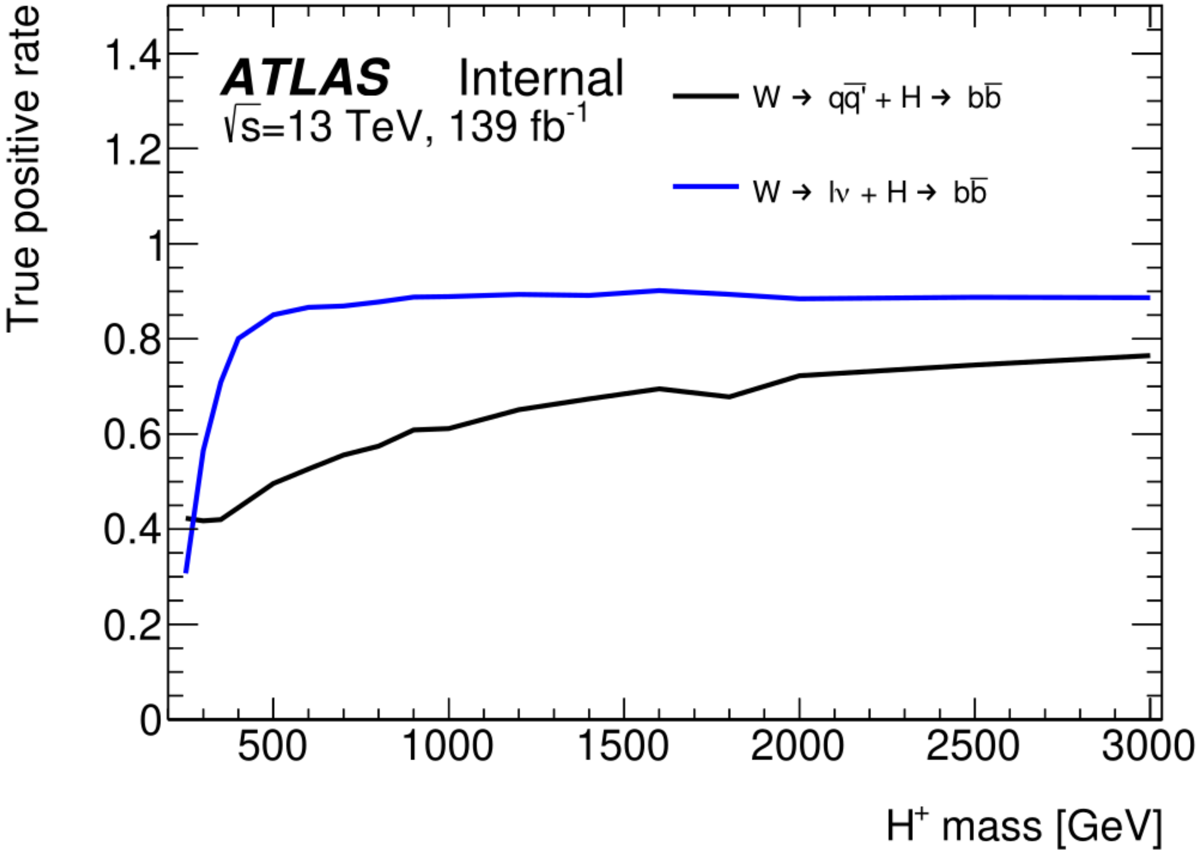
Good separation for high H^+ masses



Very little background in lvbb channel

Signal classification: performance





ratio of true lvbb events passing the requirement on m_{top} to the total number of true lvbb event

ratio of true lvbb events passing the m_{top} requirement to the total number of events passing the selection requirement on m_{top}

Reconstruction BDT

- Train a BDT to solve the jet combinatorics thus reconstructing the H+ decay
- Signal: jet-jet(qqbb)/MET+lepton(lvbb) dR matched to truth W and jet-pair dR matched to truth h
- Combinatorial background: all other jet-jet/MET+lepton jet-jet combinations
- Train using all signal mass points (250-3000 GeV)

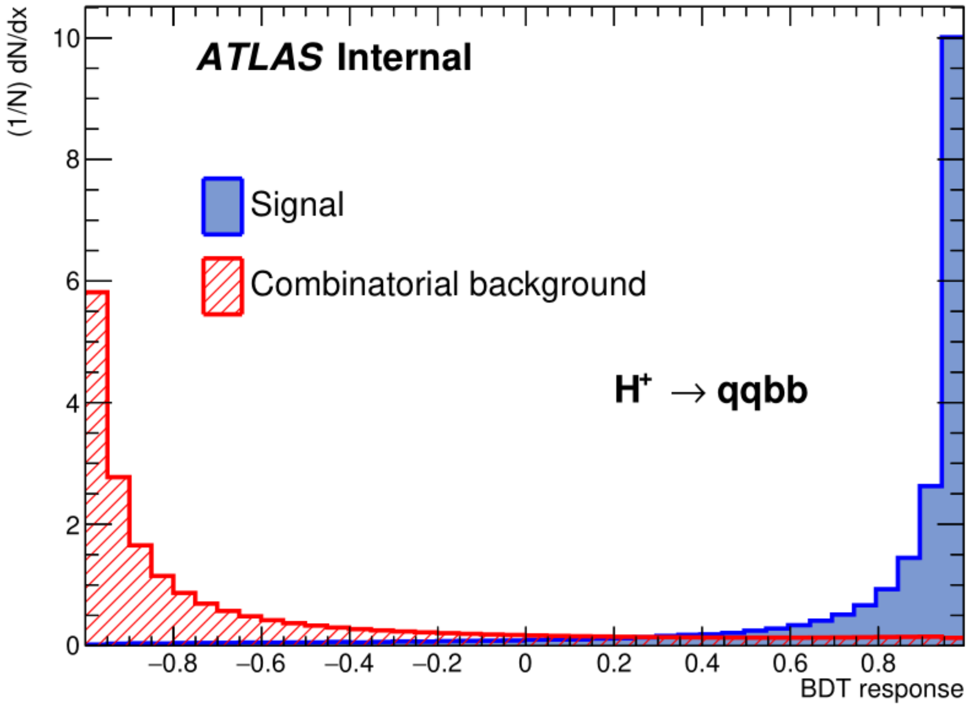
lvbb:

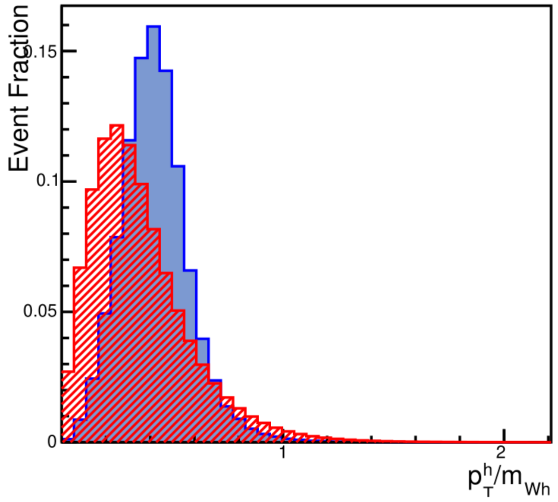
Variable name	Variable importance
$p_{\mathrm{T}}^{h}/m_{Wh}$	0.181
$p_{\mathrm{T}}^{W}/m_{Wh}$	0.166
$\lvert\Delta\eta(Wh)\rvert$	0.166
Higgs boson mass	0.146
$\Delta\Phi(h, W)$	0.144
PC b-tag first jet	0.102
PC b-tag second jet	0.096

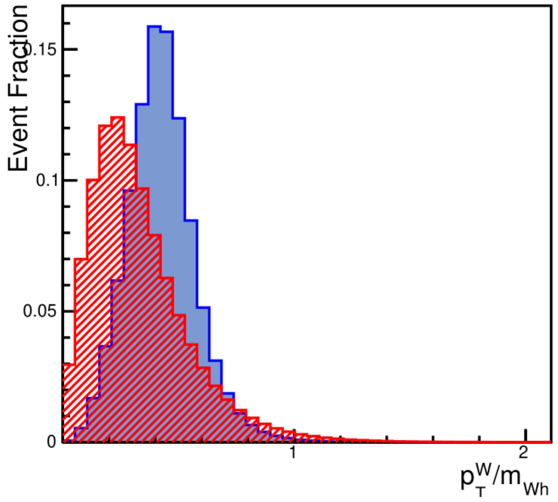
qqbb:

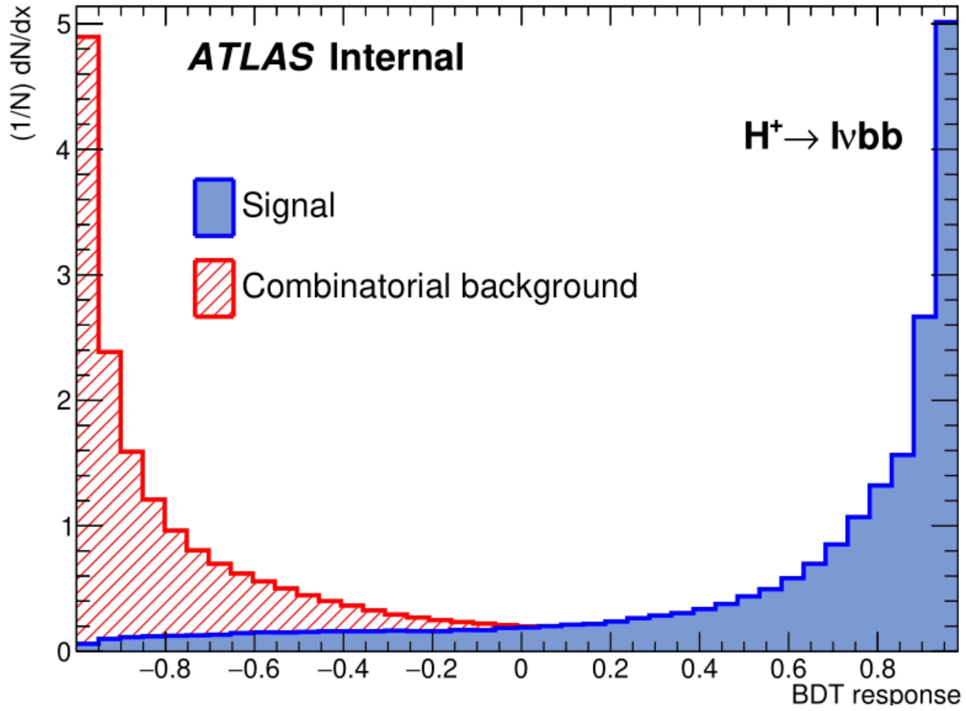
Variable name	Variable importance
$p_{\mathrm{T}}^{h}/m_{Wh}$	0.130
$\lvert\Delta\eta(Wh)\rvert$	0.128
$p_{\mathrm{T}}^{W}/m_{Wh}$	0.128
$m_{j_{h1}j_{h2}}$	0.119
$m_{j_{W1}j_{W2}}$	0.115
$\lvert\Delta\Phi(h, W)\rvert$	0.105
PC b-tag j_{h1}	0.081
PC b-tag j_{h2}	0.071
PC b-tag j_{W1}	0.063
PC b-tag j_{W2}	0.059

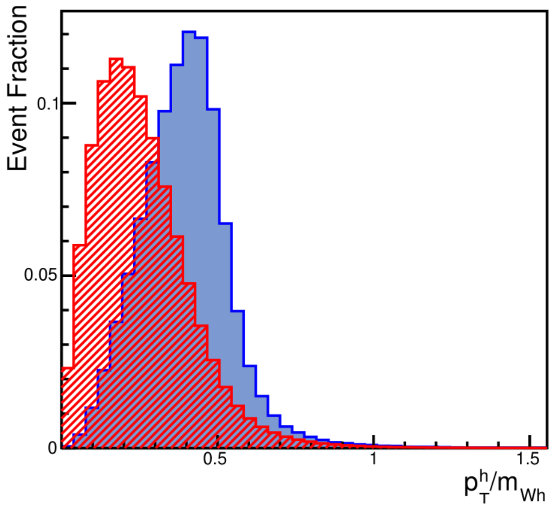
BDT Training Results

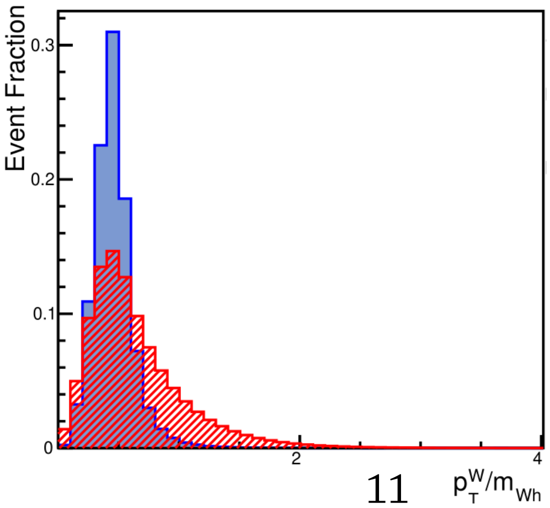






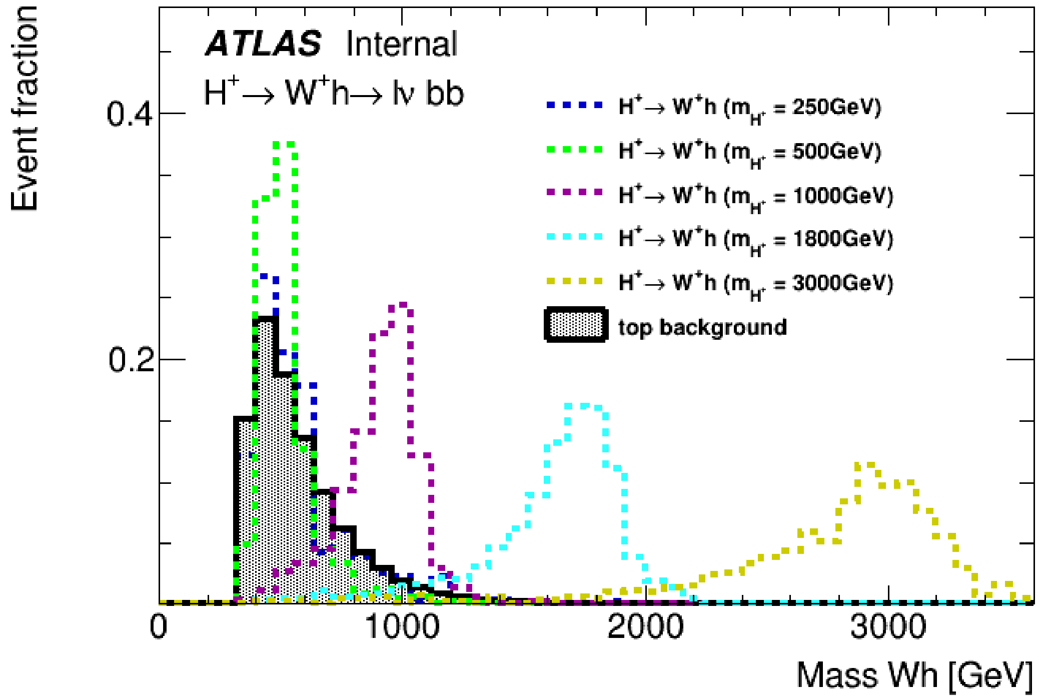


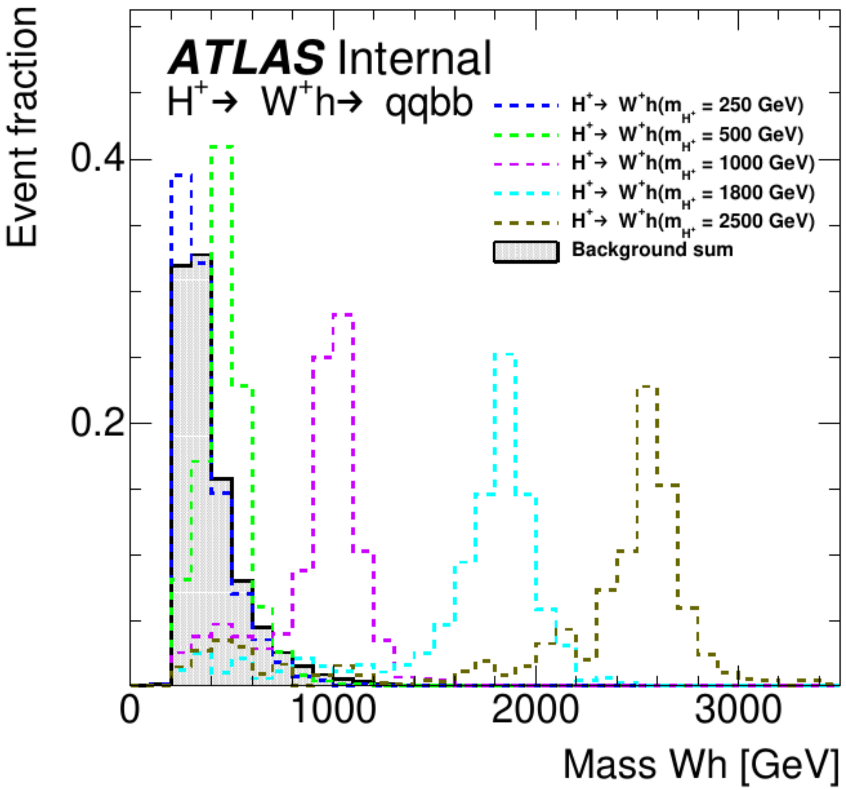




H^+ signal reconstruction: BDT application

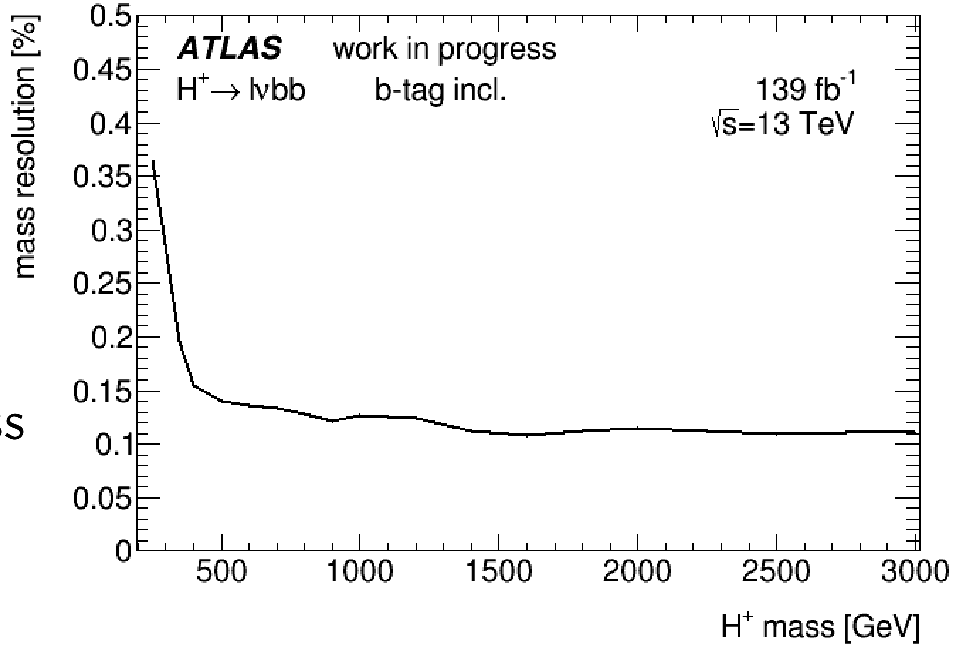
- Reconstruct top to classify events into: lvbb or qqbb
- Evaluate BDT for all possible lvjj/qqqq combinations in the event
- Choose the $H^+ \to$lvbb/qqbb candidate with the highest BDT score (max BDT response) as H^+
- The BDT successfully reconstructs the H^+ decay

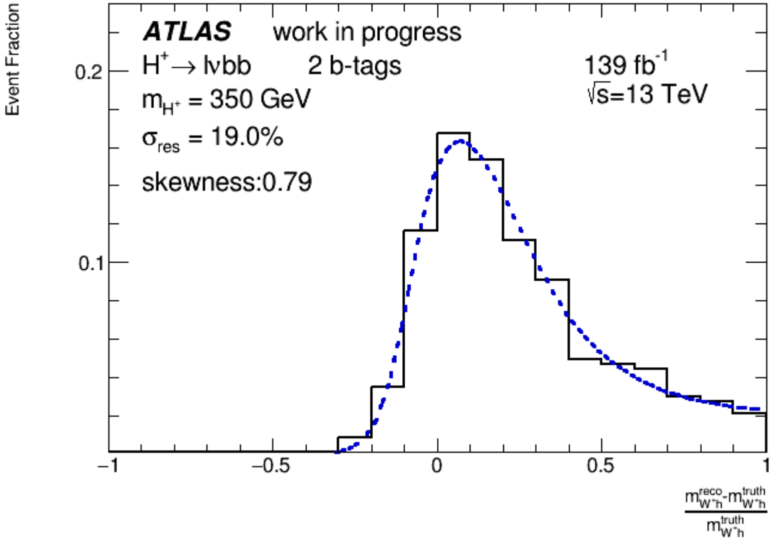


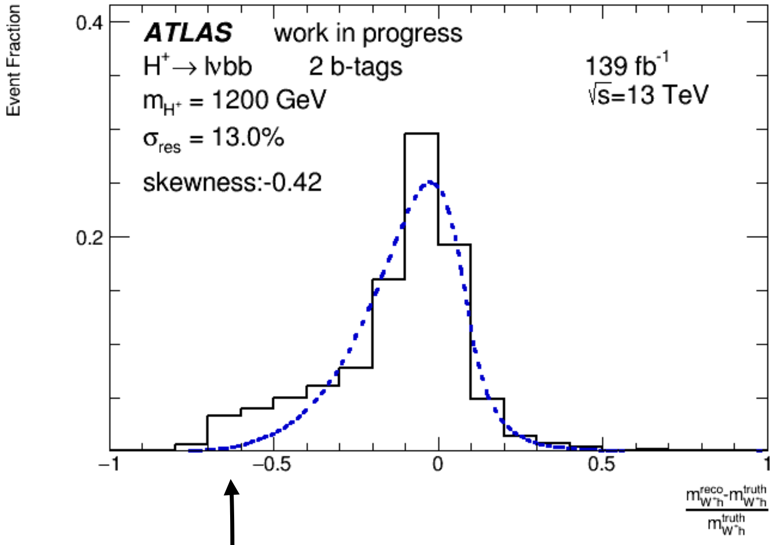


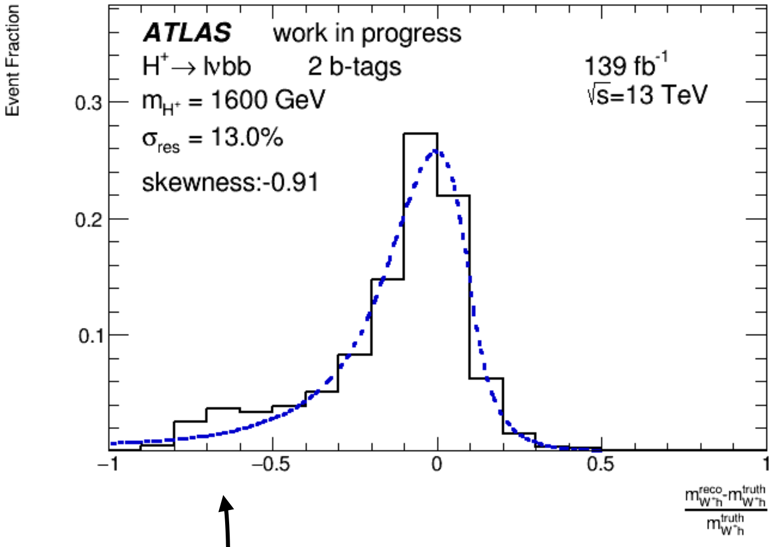
Signal mass resolution

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





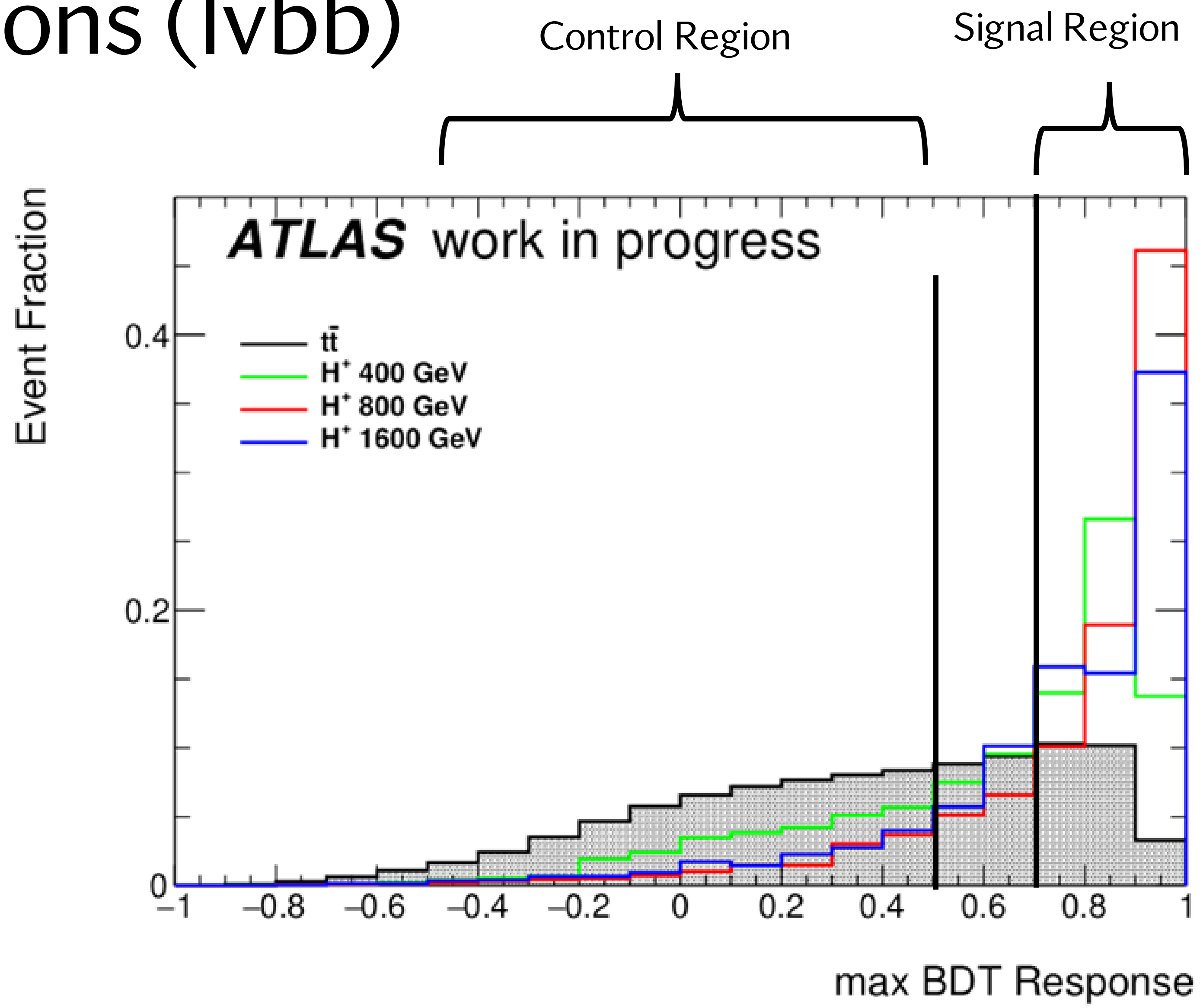




$H^+ \to qqbb$ events classified as $l\nu bb$

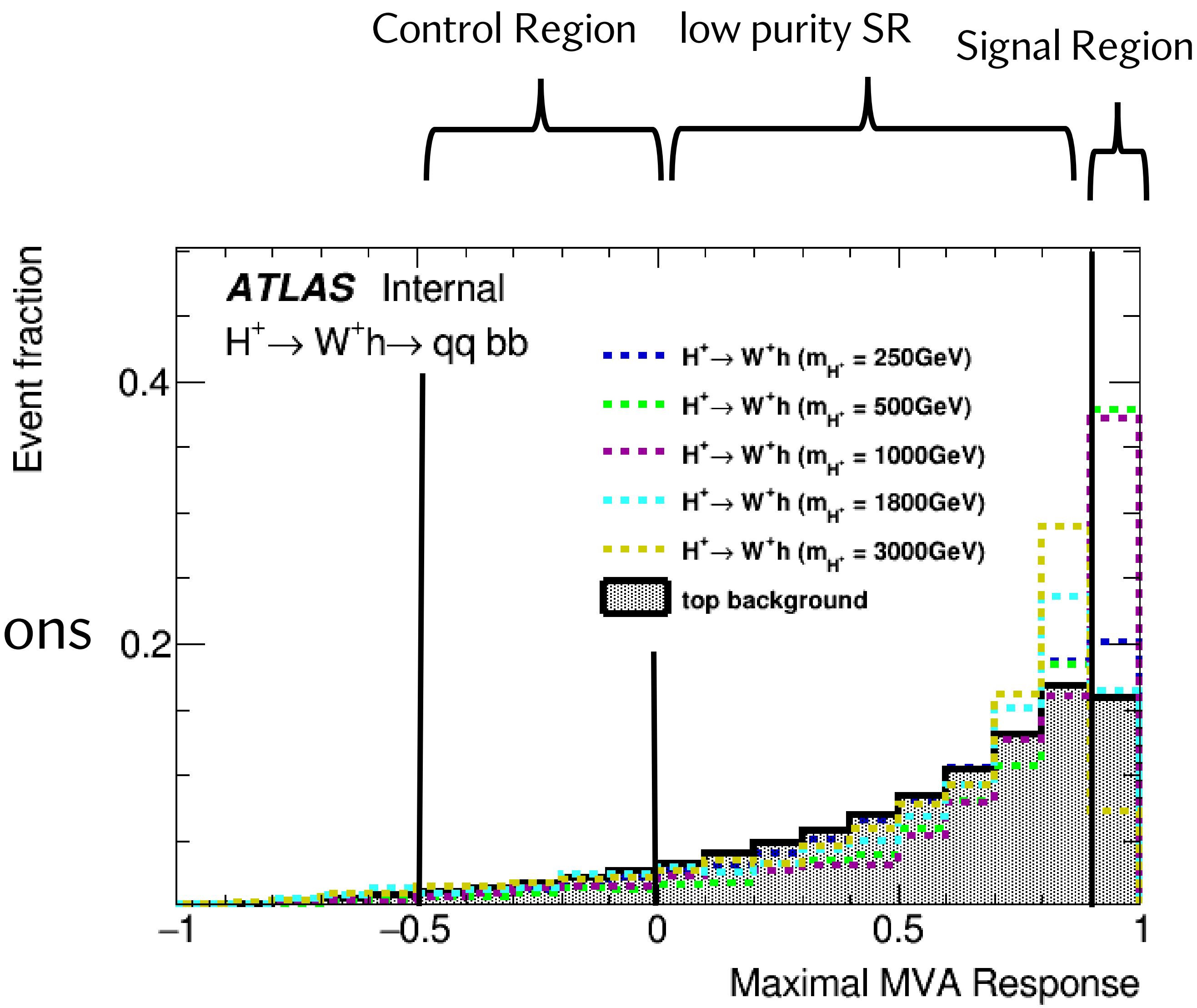
Signal and Control regions (lvbb)

- The maximal BDT Response is distinct between the signal and the background
  - tt is the dominant background source
- 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 (lvbb): w_{BDT}>0.7
- Control Region (lvbb): -0.5> w_{BDT}> 0.5



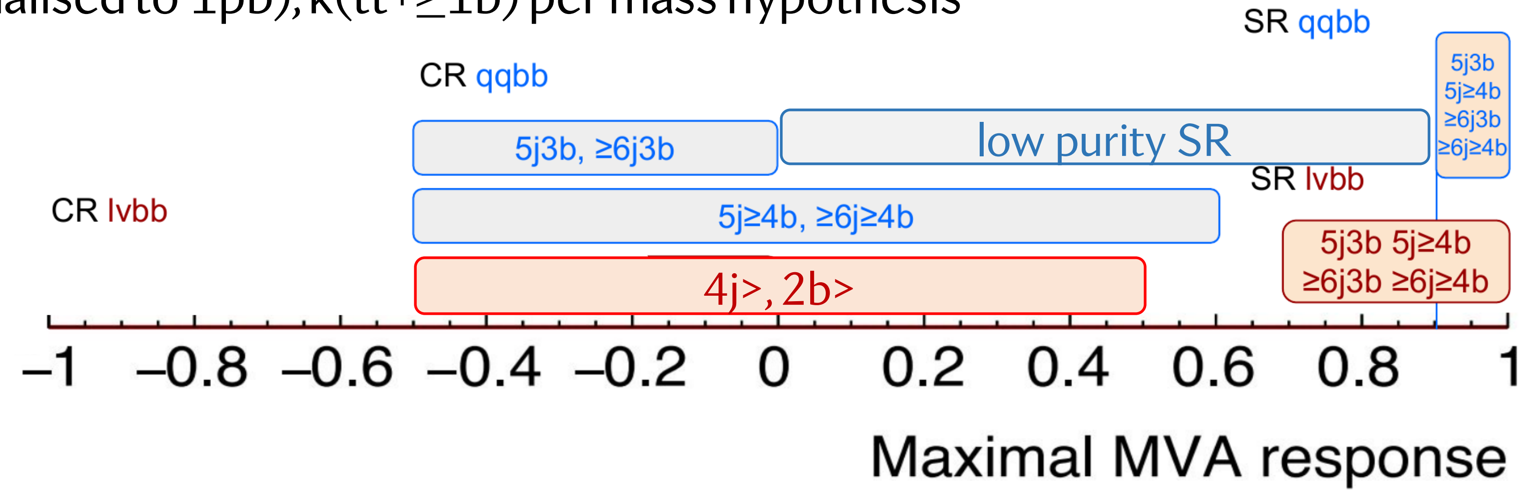
Signal and Control regions(qqbb)

- Less separation between signal and background
  - Tighter cuts are necessary
- Signal region(qqbb): w_{BDT} >0.9
- Control region(qqbb): -0.5>w_{BDT} >0.0
- Use the "gap" as a low purity signal regions
  - Improved the limits for low masses

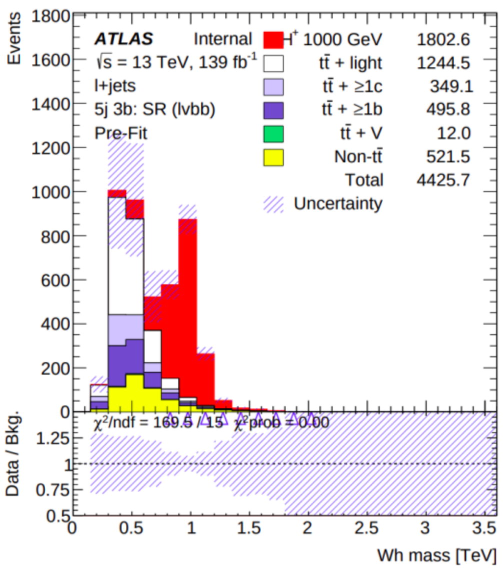


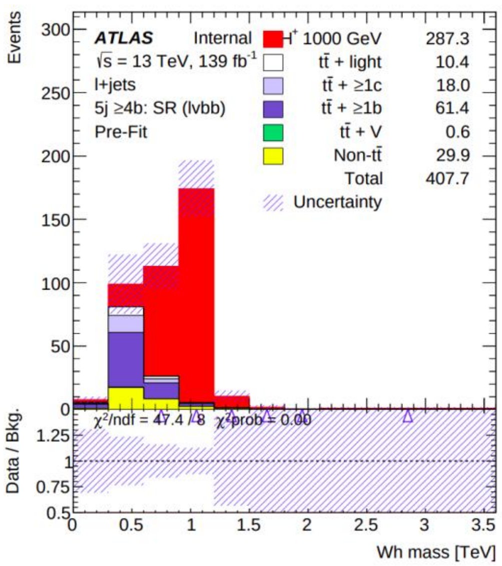
Fit setup

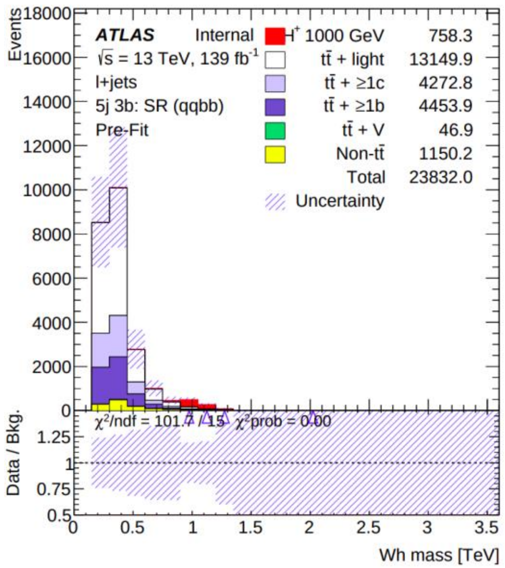
- Perform binned maximum likelihood fit
  - Fit the reconstructed H+ mass (m _WH)
  - Fit 20 regions (4 lvbb CRs, 4 lvbb SRs, 4 qqbb CRs, 4 qqbb SRs, 4 low purity qqbb SRs)
  - Use max BDT Response variable to define signal and control regions
    - Further split the regions by b-tag multiplicity
      - 3 b-tags and 4+ b-tags
    - and Jet multiplicity
      - 5 jets and 6+ jets
- Perform fit in the lvbb and qqbb channels simultaneously
- Fit μ (signal normalised to 1pb), k($t\bar{t}$+≥1b) per mass hypothesis

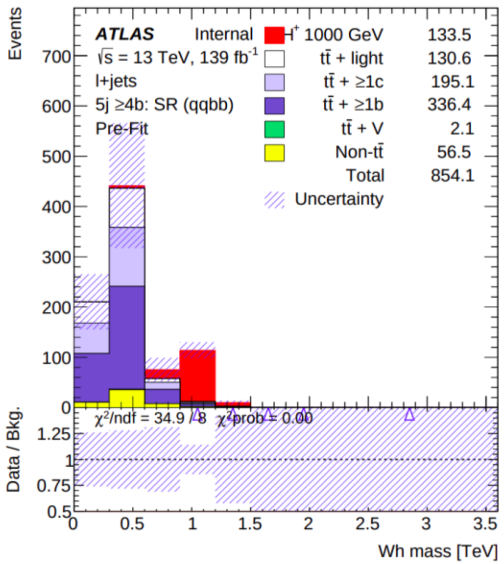


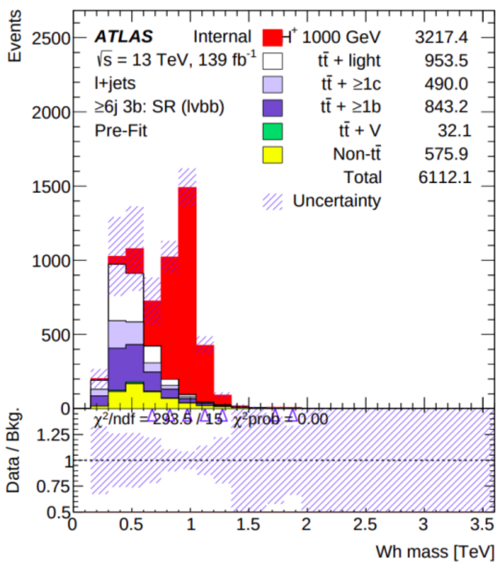
Signal region m_{Wh} distributions

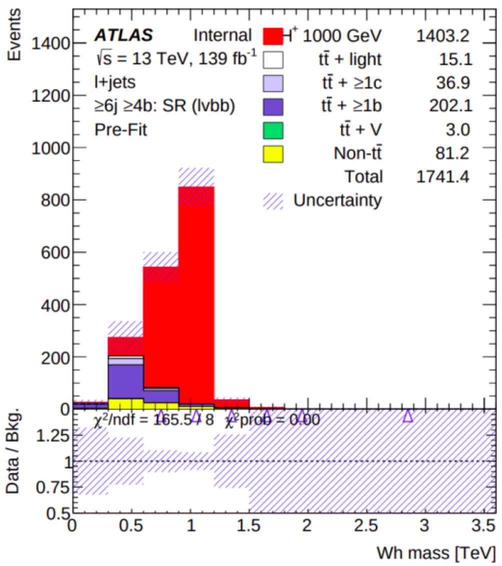


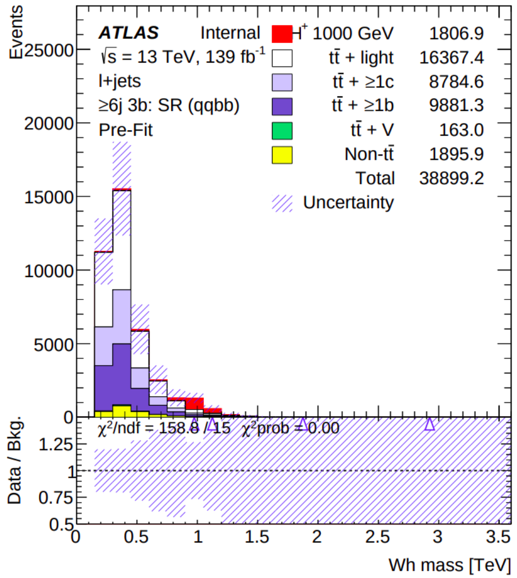


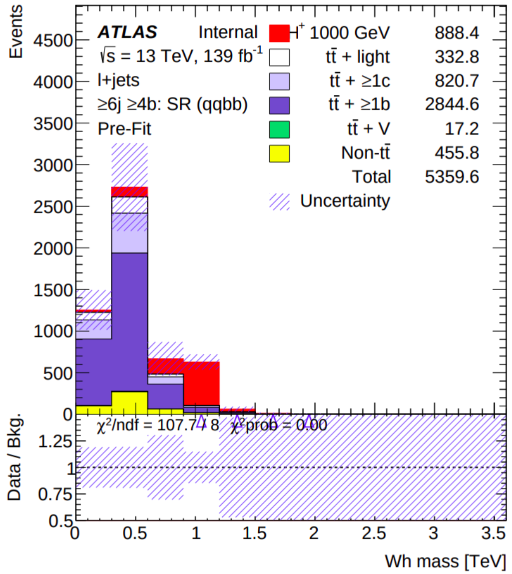






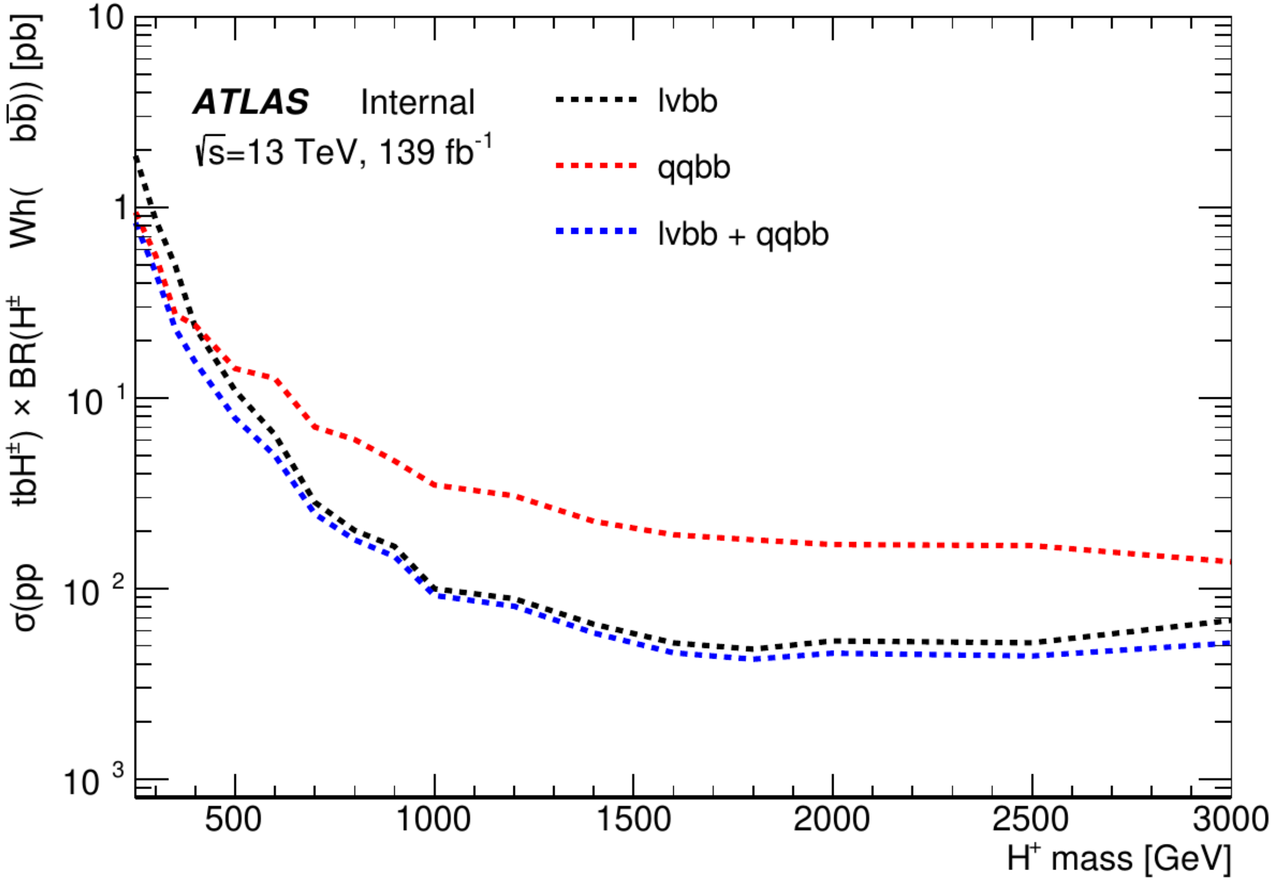


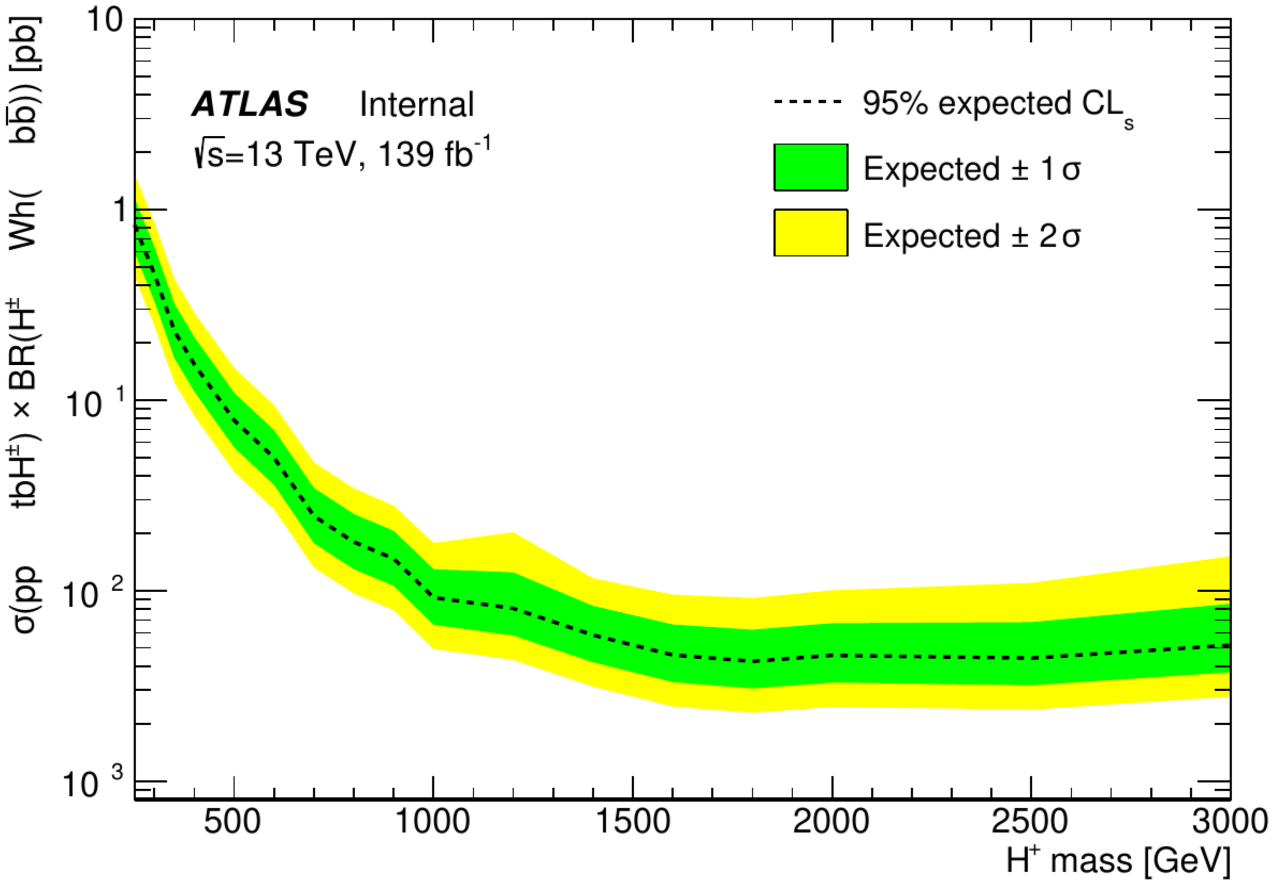




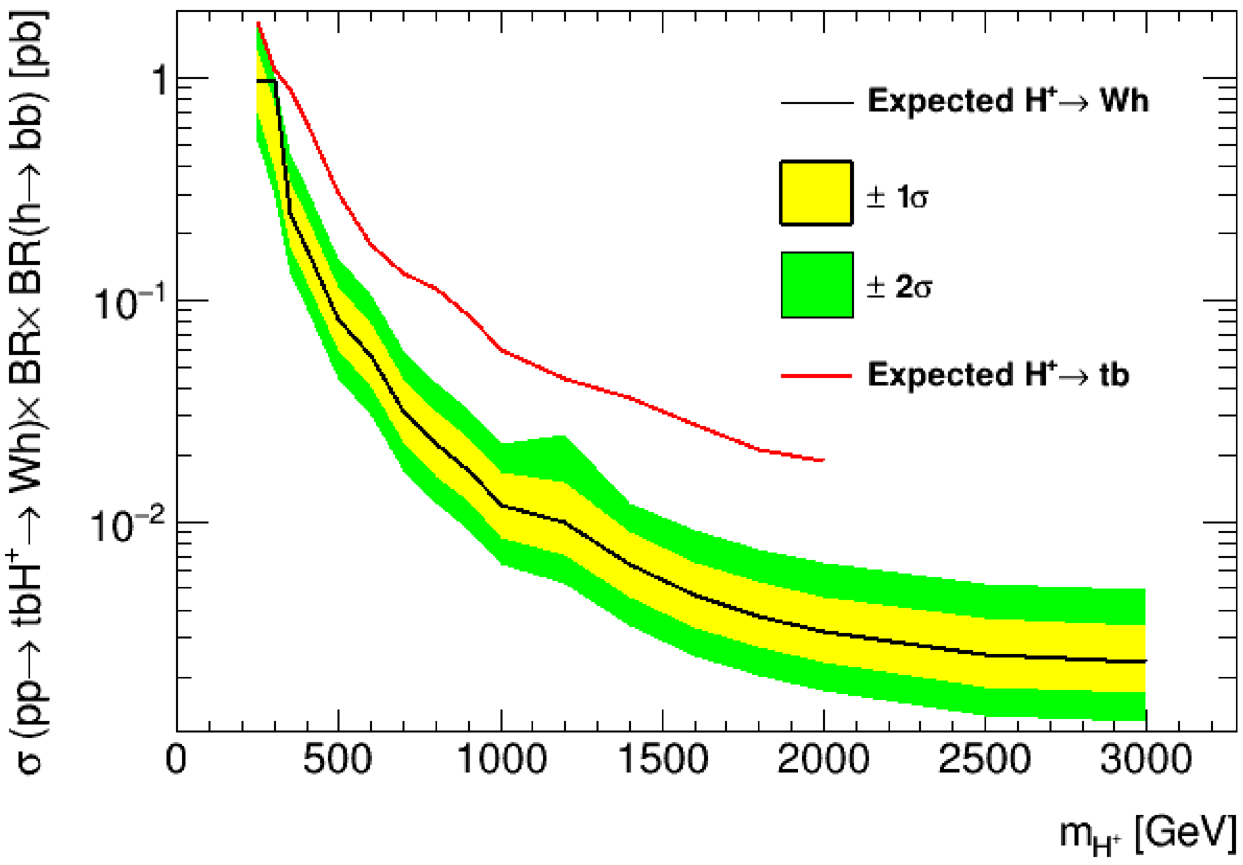
Expected upper limits

- Expected limits are calculated using an Asimov fit in all 20 region and including the full systematics





Expected limits comparison



- Expected limits are competitive with $H^+ \rightarrow tb$ [https://arxiv.org/abs/2102.10076]
  - Both states study very similar final state
  - Background contributions are also similar
  - (Wh limits shown here are with an older fit-setup)

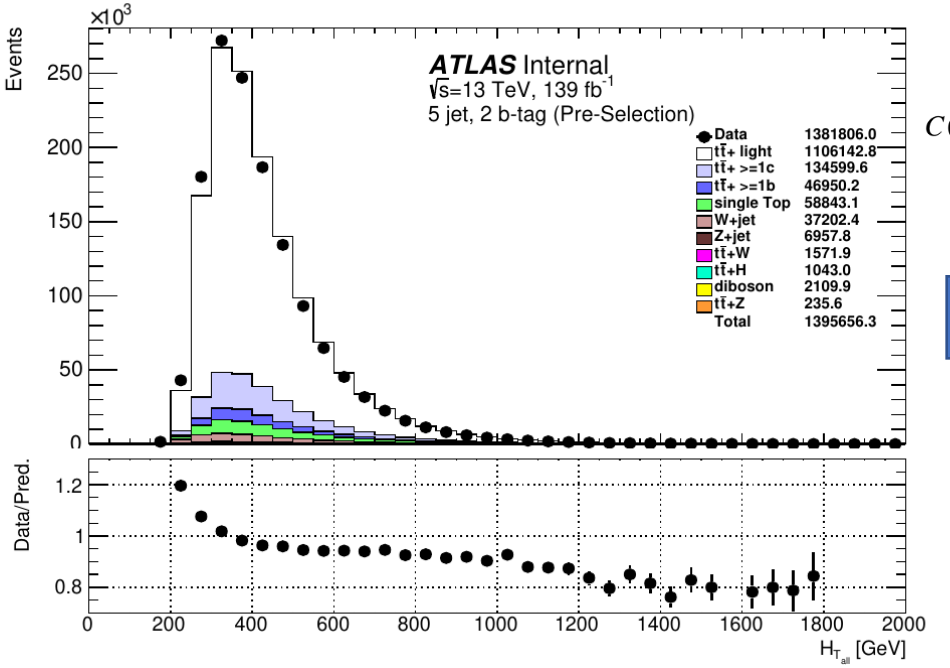
Summary/Conclusion

- $H^+ \rightarrow Wh$ studied for the first time at the LHC
  - Complementary to other H^+ searches e.g $H^+ \rightarrow tb$
- A full analysis strategy for the H+ → Wh search was developed
  - The mass of a reconstructed t is used to distinguish between $H^+ \rightarrow l\nu bb$ and $H^+ \rightarrow qqbb$ decay
  - Boosted decision trees are successfully used to to reconstruct the $H^+ \rightarrow Wh$ decay out of a complicated final state
  - Expected limits are competitive with existing H^+ searches
- Just stared the unblinding process (unblinded the low purity qqbb SRs)
- Next Steps:
  - Fully unblind
  - Aim to present first public results at the Higgs-Hunting conference(12 September)

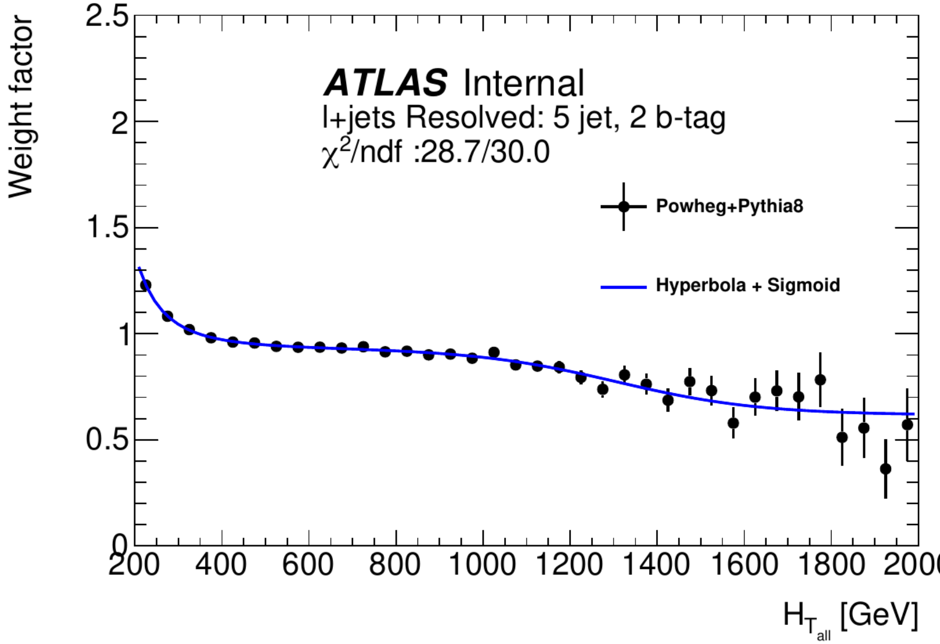
Backup

tt+ jets reweighting

- Derive correction factor to compensate known $t\bar{t}$ mismodeling
- Derive correction factors in the 2 b-tag region as a function of HT (scalar sum of all visible transvers momenta)
  1. Derive Correction factors from the Data-MC ratio for each jet multiplicity
  2. Fit hyperbola + sigmoid function
  3. Apply the HT all correction factors on 3b and ≥4b regions



$$C(H_T^{all}) = \frac{N^{data}(H_T^{all}) - N^{non-t\bar{t}}(H_T^{all})}{N^{t\bar{t}}(H_T^{all})}$$



Further material in the fit

Systematic uncertainties

- Introduce systematic uncertainties as NP correlated among all regions
- 0.5% pruning threshold
- tt̄+jets modelling split in tt̄+≥1b, tt̄+≥1c and tt̄+light components
- Added qqbb VR to SR/CR extrapolation uncertainties
- Missing uncertainties
  - Signal PS uncertainties
  - Signal PDF uncertainties

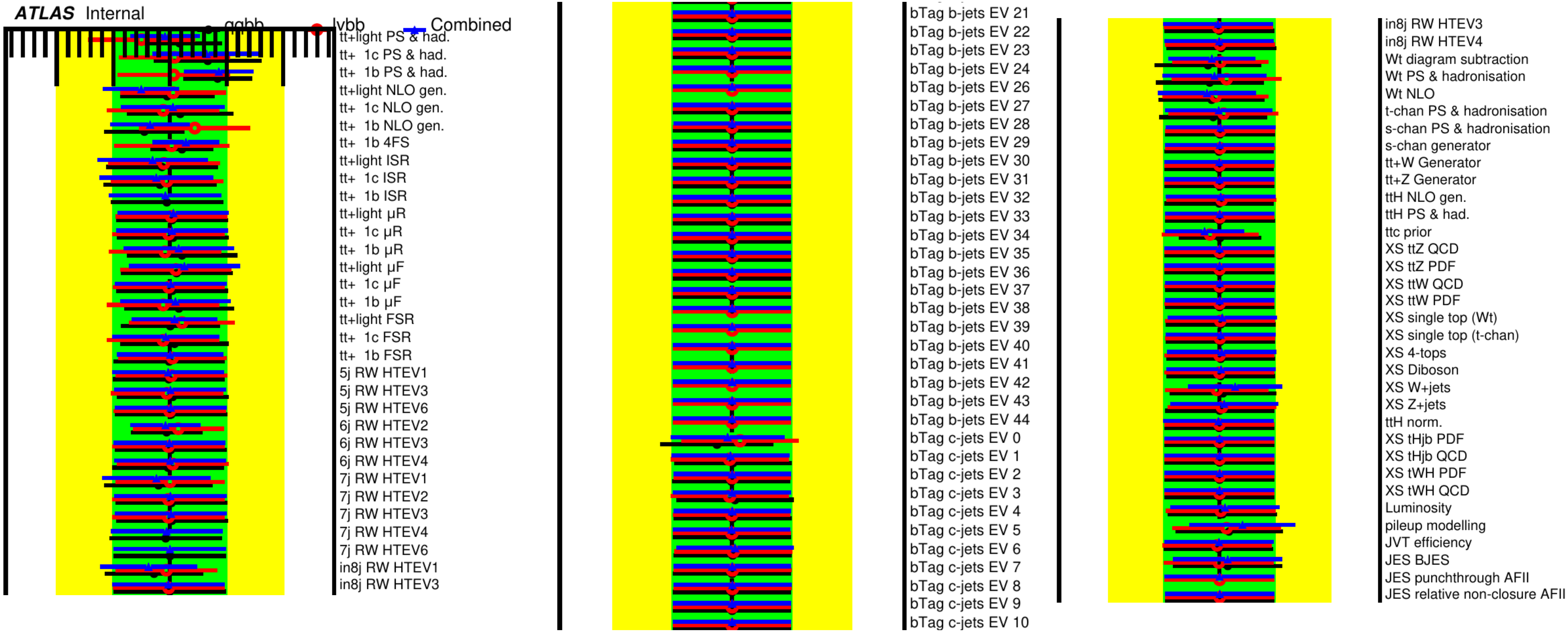
Systematic uncertainty	Type	Components
Experimental uncertainties		
Luminosity	N	1
Pileup modeling	SN	1
Physics objects		
Electrons	SN	7
Muons	SN	15
Jet energy scale	SN	31
Jet energy resolution	SN	9
Jet vertex tagger	SN	1
$E_{\mathrm{T}}^{\mathrm{miss}}$	SN	3
b-tagging		
Efficiency	SN	45
Mis-tag rate (c)	SN	20
Mis-tag rate (light)	SN	20
PCBT high pT extrapolation	SN	3
Signal and background modeling		
Signal		
PDF variations	SN	30
Scales	SN	2
$t\bar{t}$ background		
$t\bar{t}$ cross-section	N	1
PDF variations	SN	30
$t\bar{t}$ reweighting	SN	24
$t\bar{t}+\geq 1b$ normalisation	N (free floating)	1
$t\bar{t}+$ light modelling	SN	6
$t\bar{t}+\geq 1c$ modelling	SN	6
$t\bar{t}+\geq 1b$ modelling	S	7
Transfer factor uncertainties	N	5
Other backgrounds		
$t\bar{t}W$ cross-section	N	2
$t\bar{t}Z$ cross-section	N	2
$t\bar{t}W$ modelling	SN	1
$t\bar{t}Z$ modelling	SN	1
$t\bar{t}H$ cross-section	N	1
$t\bar{t}H$ modelling	SN	2
Single top cross-section	N	6
Single top modeling	SN	7
W+jets normalisation	N	1
Z+jets normalisation	N	1
Diboson normalisation	N	1
$t\bar{t}t\bar{t}$ cross-section	N	1
Small backgrounds cross-sections	N	4

Uncertainty source	Description		Components
$t\bar{t}+\geq 1c$ prior	Up or down by 50%		$t\bar{t}+\geq 1c$
$t\bar{t}$ reweighting	Statistical uncertainties of weights		All $t\bar{t}$
$t\bar{t}+\geq 1b$ modelling	4FS vs 5FS		$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ normalisation	Free-floating		$t\bar{t}+\geq 1b$
Transfer factor uncertainties	see. sec.xxx	$t\bar{t}+\geq 1b$	
NLO matching	MG5_aMC@NLO+Pythia8	vs. Powheg+Pythia8 (AFII)	All
PS & hadronisation	Powheg+Herwig	vs. Powheg+Pythia8 (AFII)	All
α_S^{ISR}	*Var3cUp* (*Var3cDown*)	in Powheg+Pythia8	All
μ_f	scaling by 0.5 (2.0)	in Powheg+Pythia8	All
μ_r	scaling by 0.5 (2.0)	in Powheg+Pythia8	All
FSR	Varying α_S^{FSR} (PS)	in Powheg+Pythia8	All

Nuisance Parameter	Description	Value
XS_ttW	Normalisation of the $t\bar{t}+W$ background	QCD (±10%), PDF (±4%)
XS_ttZ	Normalisation of the $t\bar{t}+Z$ background	QCD (±12%), PDF (±3.4%)
XS_Wt	Normalisation of the Wt background	±5%
XS_sch	Normalisation of the s-channel single top background	±5%
XS_tch	Normalisation of the t-channel single top background	±5%
XS_tZ	Normalisation of the tZ background	PDF (±0.9%), QCD (±7.9%)
XS_tWZ	Normalisation of the tWZ background	±50%
XS_Wjets	Normalisation of the W+jets background	±40%
XS_Zjets	Normalisation of the Z+jets background	±35%
XS_Diboson	Normalisation of the diboson background	±50%
XS_ttH	Normalisation of the $t\bar{t}H$ background	$^{+9\%}_{-12\%}$
XS_4top	Normalisation of the four top background	±50%
XS_tHjb	Normalisation of the $tHjb$ background	QCD ($^{+6.5\%}_{-14.9\%}$), PDF (±3.7%)
XS_tWH	Normalisation of the tWH background	QCD ($^{+6.5\%}_{-6.7\%}$), PDF (±6.3%)

Data-MC comparions/Bkg only fit

NP-pulls



ATLAS Internal
qqbb
lvbb
Combined
tt+light PS & had.
tt+ 1c PS & had.
tt+ 1b PS & had.
tt+light NLO gen.
tt+ 1c NLO gen.
tt+ 1b NLO gen.
tt+ 1b 4FS
tt+light ISR
tt+ 1c ISR
tt+ 1b ISR
tt+light μR
tt+ 1c μR
tt+ 1b μR
tt+light μF
tt+ 1c μF
tt+ 1b μF
tt+light FSR
tt+ 1c FSR
tt+ 1b FSR
5j RW HTEV1
5j RW HTEV3
5j RW HTEV6
6j RW HTEV2
6j RW HTEV3
6j RW HTEV4
7j RW HTEV1
7j RW HTEV2
7j RW HTEV3
7j RW HTEV4
7j RW HTEV6
in8j RW HTEV1
in8j RW HTEV3
bTag b-jets EV 21
bTag b-jets EV 22
bTag b-jets EV 23
bTag b-jets EV 24
bTag b-jets EV 26
bTag b-jets EV 27
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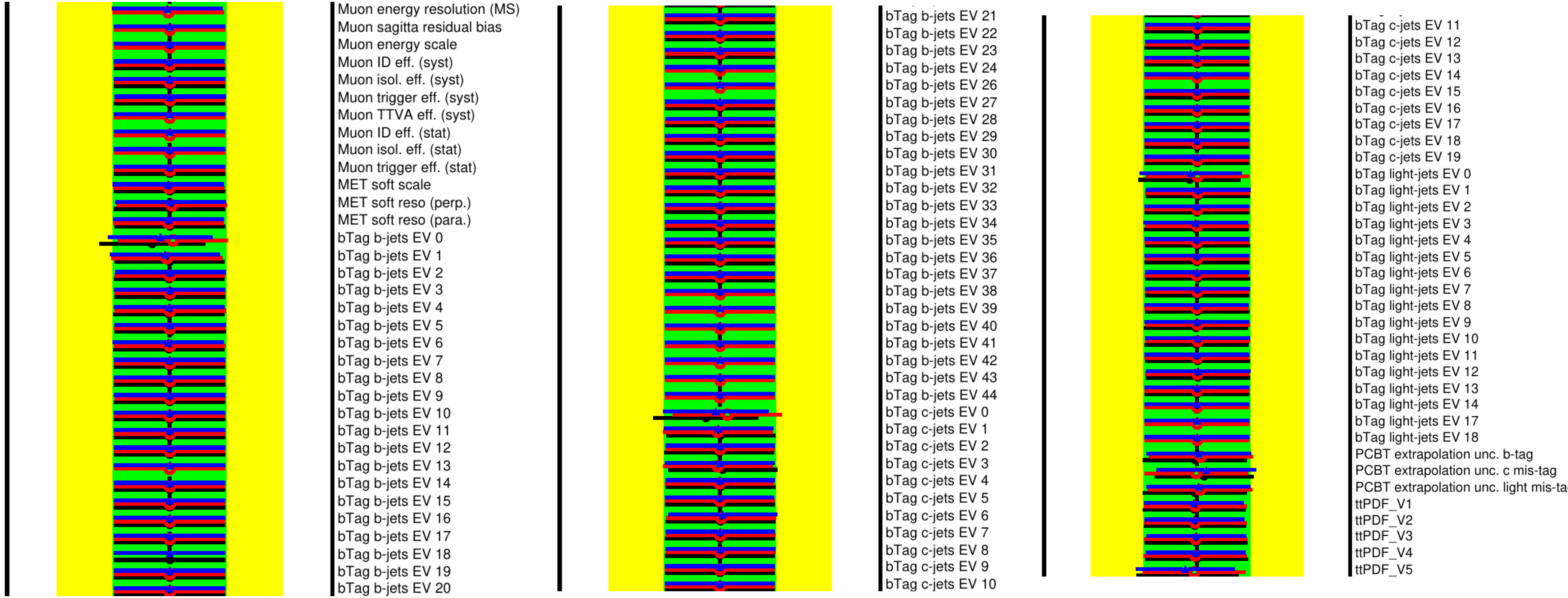
bTag b-jets EV 42
bTag b-jets EV 43
bTag b-jets EV 44
bTag c-jets EV 0
bTag c-jets EV 1
bTag c-jets EV 2
bTag c-jets EV 3
bTag c-jets EV 4
bTag c-jets EV 5
bTag c-jets EV 6
bTag c-jets EV 7
bTag c-jets EV 8
bTag c-jets EV 9
bTag c-jets EV 10
in8j RW HTEV3
in8j RW HTEV4
Wt diagram subtraction
Wt PS & hadronisation
Wt NLO
t-chan PS & hadronisation
s-chan PS & hadronisation
s-chan generator
tt+W Generator
tt+Z Generator
ttH NLO gen.
ttH PS & had.
ttc prior
XS ttZ QCD
XS ttZ PDF
XS ttW QCD
XS ttW PDF
XS single top (Wt)
XS single top (t-chan)
XS 4-tops
XS Diboson
XS W+jets
XS Z+jets
ttH norm.
XS tHjb PDF
XS tHjb QCD
XS tWH PDF
XS tWH QCD
Luminosity
pileup modelling
JVT efficiency
JES BJES
JES punchthrough AFII
JES relative non-closure AFII


Muon energy resolution (MS)
Muon sagitta residual bias
Muon energy scale
Muon ID eff. (syst)
Muon isol. eff. (syst)
Muon trigger eff. (syst)
Muon TTVA eff. (syst)
Muon ID eff. (stat)
Muon isol. eff. (stat)
Muon trigger eff. (stat)
MET soft scale
MET soft reso (perp.)
MET soft reso (para.)
bTag b-jets EV 0
bTag b-jets EV 1
bTag b-jets EV 2
bTag b-jets EV 3
bTag b-jets EV 4
bTag b-jets EV 5
bTag b-jets EV 6
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bTag b-jets EV 42
bTag b-jets EV 43
bTag b-jets EV 44
bTag c-jets EV 0
bTag c-jets EV 1
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bTag c-jets EV 3
bTag c-jets EV 4
bTag c-jets EV 5
bTag c-jets EV 6
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bTag c-jets EV 16
bTag c-jets EV 17
bTag c-jets EV 18
bTag c-jets EV 19
bTag light-jets EV 0
bTag light-jets EV 1
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bTag light-jets EV 7
bTag light-jets EV 8
bTag light-jets EV 9
bTag light-jets EV 10
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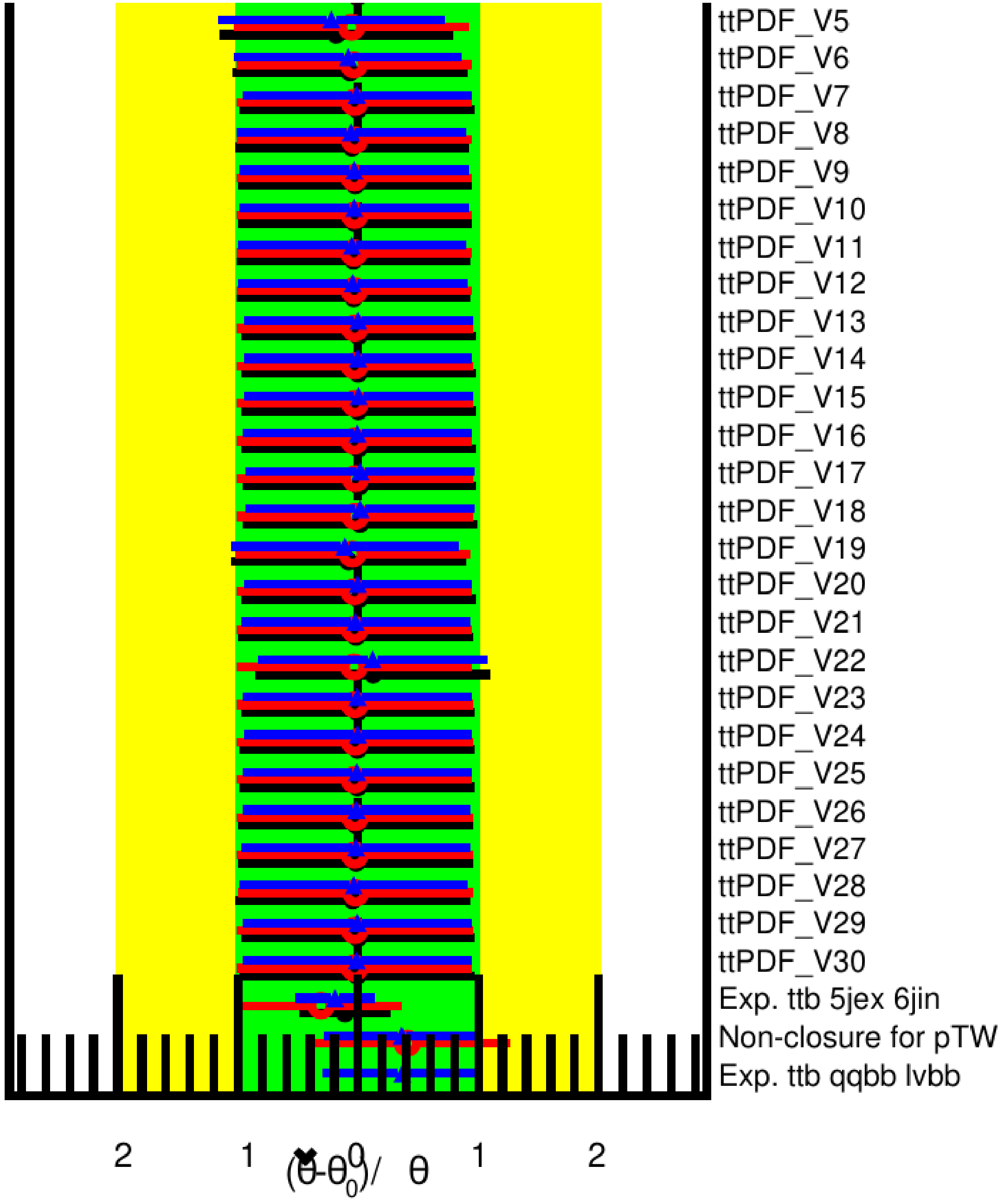
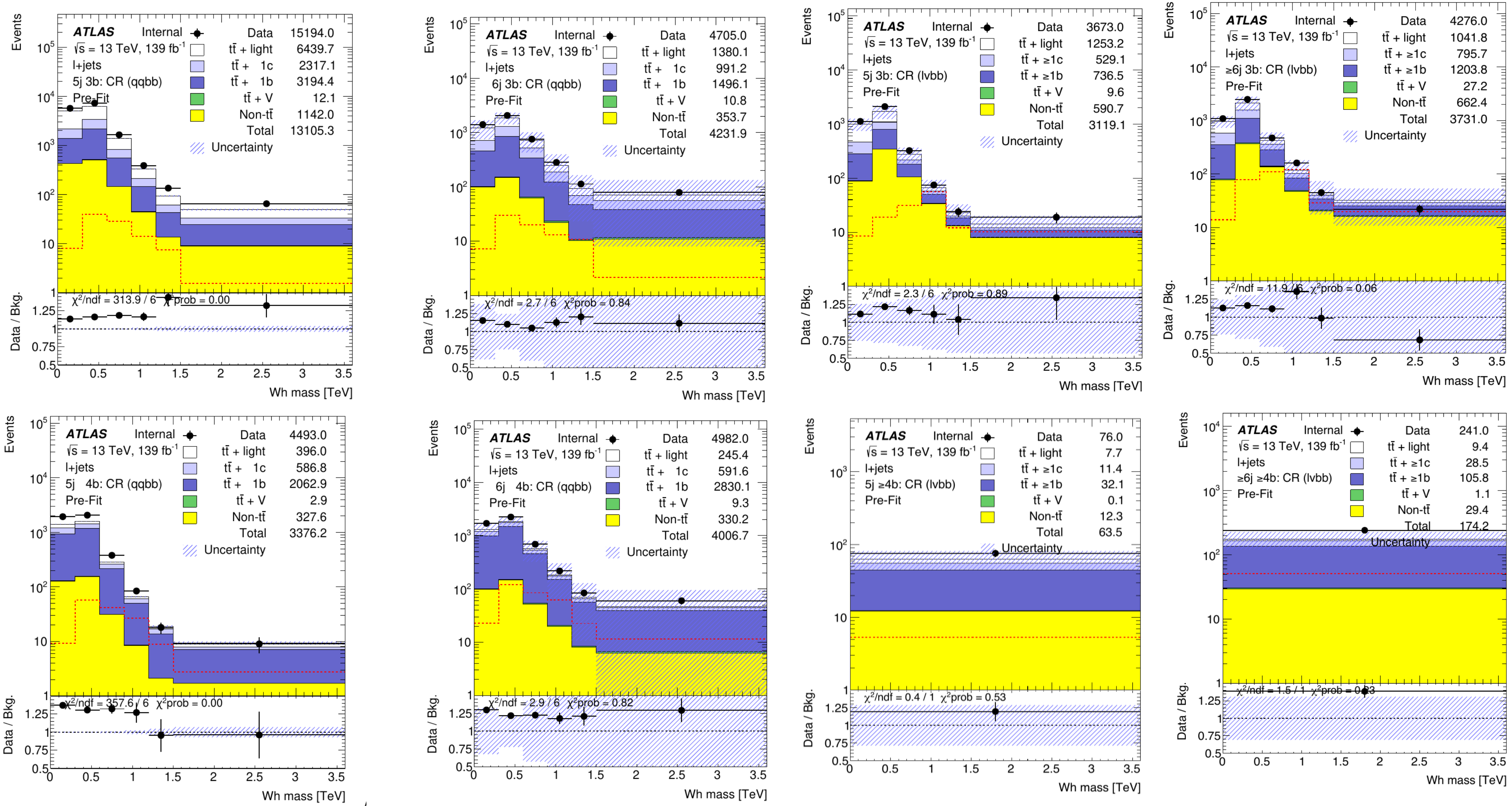
bTag light-jets EV 13
bTag light-jets EV 14
bTag light-jets EV 17
bTag light-jets EV 18
PCBT extrapolation unc. b-tag
PCBT extrapolation unc. c mis-tag
PCBT extrapolation unc. light mis-ta
ttPDF_V1
ttPDF_V2
ttPDF_V3
ttPDF_V4
ttPDF_V5

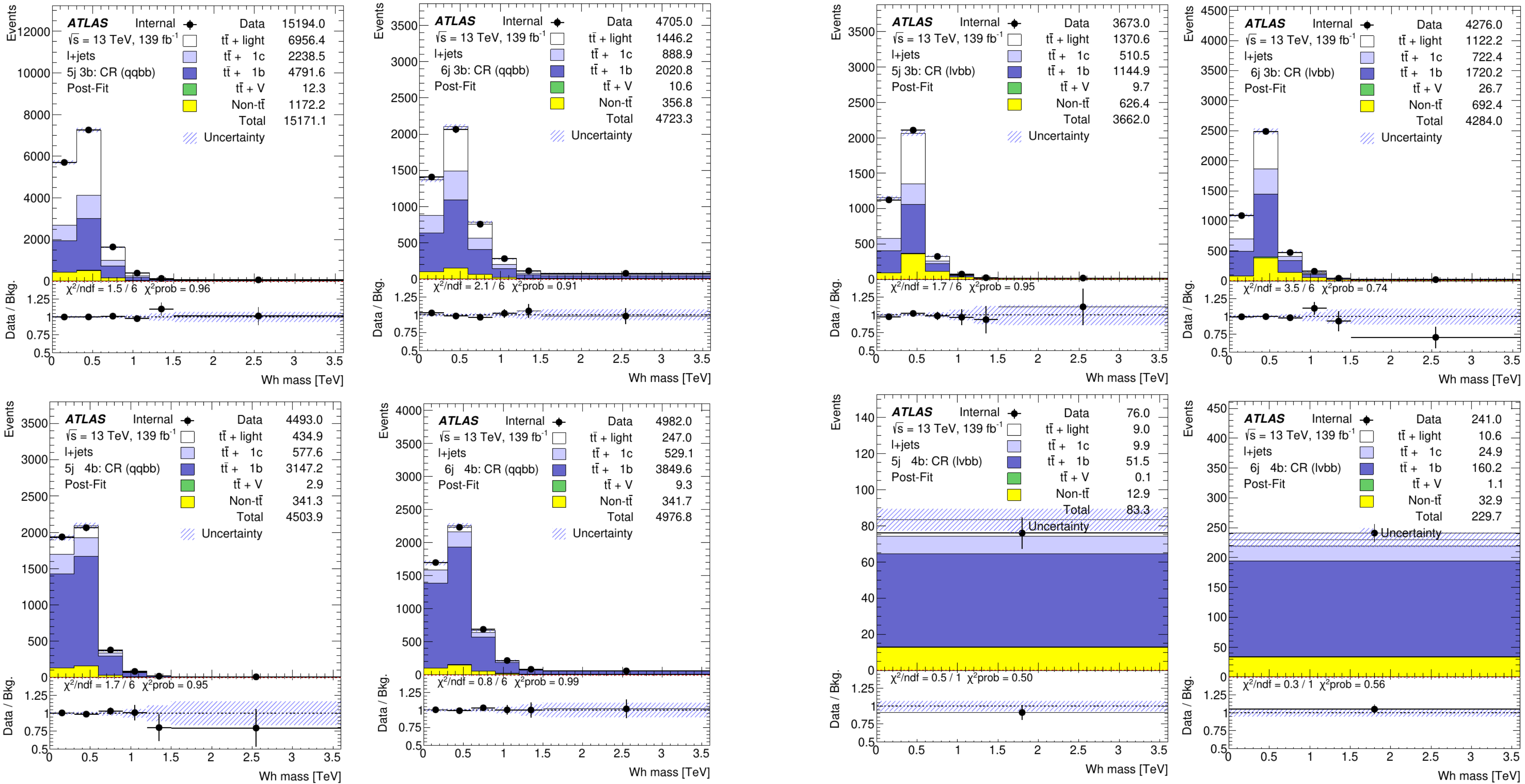


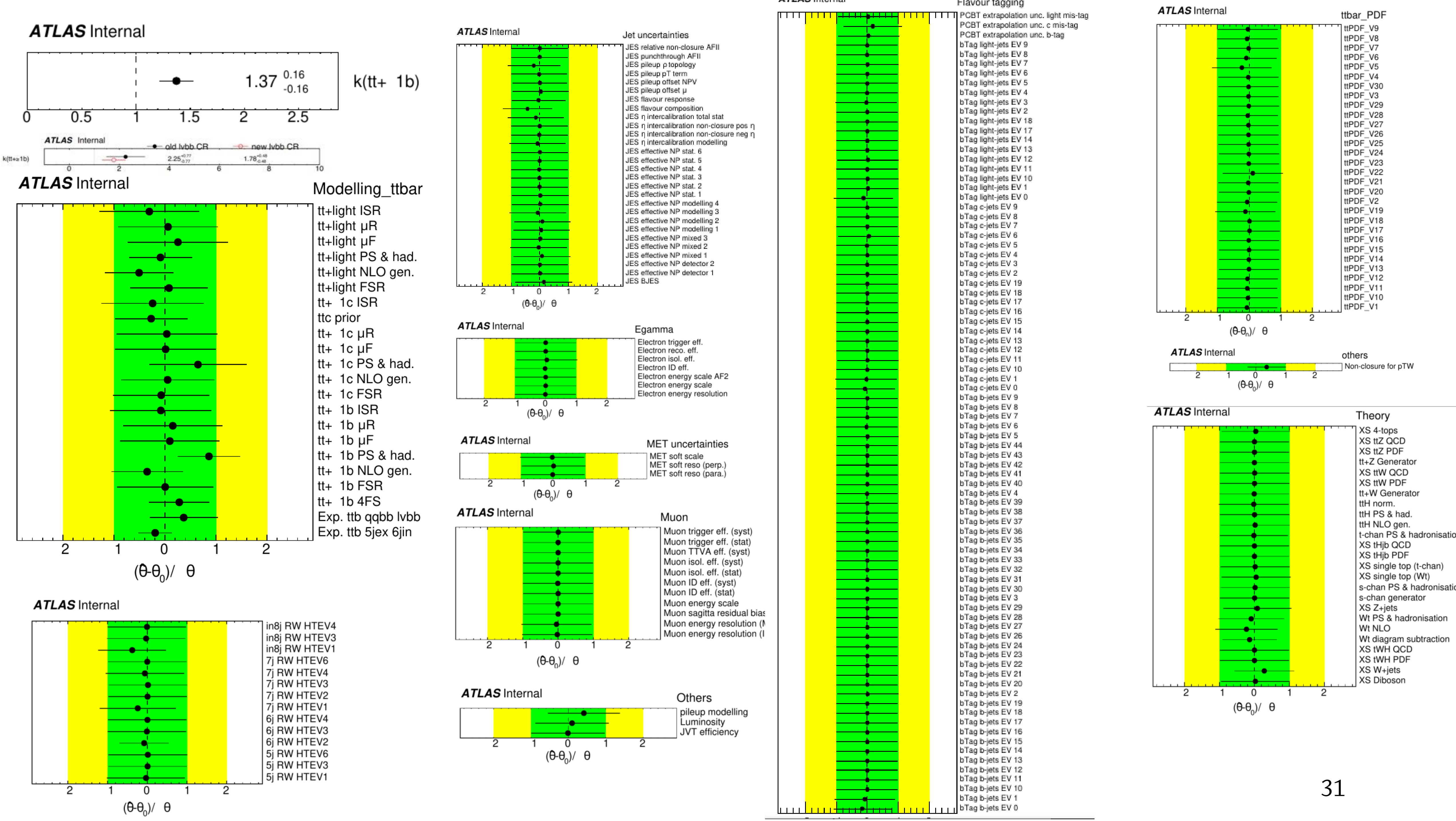
ttPDF_V5
ttPDF_V6
ttPDF_V7
ttPDF_V8
ttPDF_V9
ttPDF_V10
ttPDF_V11
ttPDF_V12
ttPDF_V13
ttPDF_V14
ttPDF_V15
ttPDF_V16
ttPDF_V17
ttPDF_V18
ttPDF_V19
ttPDF_V20
ttPDF_V21
ttPDF_V22
ttPDF_V23
ttPDF_V24
ttPDF_V25
ttPDF_V26
ttPDF_V27
ttPDF_V28
ttPDF_V29
ttPDF_V30
Exp. ttb 5jex 6jin
Non-closure for pTW
Exp. ttb qqbb lvbb
2
1
0
1
2
$(\theta-\theta_0)/\Delta\theta$

Pre-fit distributions



Post-fit distributions (BO-fit to data in the CR)




ATLAS Internal
1.37 0.16 -0.16
k(tt+ 1b)
0 0.5 1 1.5 2 2.5
ATLAS Internal
old lvbb CR
new lvbb CR
k(tt+≥1b)
2.25
1.78
0 2 4 6 8 10
ATLAS Internal
Modelling_ttbar
tt+light ISR
tt+light μR
tt+light μF
tt+light PS & had.
tt+light NLO gen.
tt+light FSR
tt+ 1c ISR
ttc prior
tt+ 1c μR
tt+ 1c μF
tt+ 1c PS & had.
tt+ 1c NLO gen.
tt+ 1c FSR
tt+ 1b ISR
tt+ 1b μR
tt+ 1b μF
tt+ 1b PS & had.
tt+ 1b NLO gen.
tt+ 1b FSR
tt+ 1b 4FS
Exp. ttb qqbb lvbb
Exp. ttb 5jex 6jin
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
in8j RW HTEV4
in8j RW HTEV3
in8j RW HTEV1
7j RW HTEV6
7j RW HTEV4
7j RW HTEV3
7j RW HTEV2
7j RW HTEV1
6j RW HTEV4
6j RW HTEV3
6j RW HTEV2
5j RW HTEV6
5j RW HTEV3
5j RW HTEV1
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
Jet uncertainties
JES relative non-closure AFII
JES punchthrough AFII
JES pileup ρ topology
JES pileup pT term
JES pileup offset NPV
JES pileup offset μ
JES flavour response
JES flavour composition
JES η intercalibration total stat
JES η intercalibration non-closure pos η
JES η intercalibration non-closure neg η
JES η intercalibration modelling
JES effective NP stat. 6
JES effective NP stat. 5
JES effective NP stat. 4
JES effective NP stat. 3
JES effective NP stat. 2
JES effective NP stat. 1
JES effective NP modelling 4
JES effective NP modelling 3
JES effective NP modelling 2
JES effective NP modelling 1
JES effective NP mixed 3
JES effective NP mixed 2
JES effective NP mixed 1
JES effective NP detector 2
JES effective NP detector 1
JES BJES
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
Egamma
Electron trigger eff.
Electron reco. eff.
Electron isol. eff.
Electron ID eff.
Electron energy scale AF2
Electron energy scale
Electron energy resolution
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
MET uncertainties
MET soft scale
MET soft reso (perp.)
MET soft reso (para.)
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
Muon
Muon trigger eff. (syst)
Muon trigger eff. (stat)
Muon TTVA eff. (syst)
Muon isol. eff. (syst)
Muon isol. eff. (stat)
Muon ID eff. (syst)
Muon ID eff. (stat)
Muon energy scale
Muon sagitta residual bias
Muon energy resolution (I
Muon energy resolution (I
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
Others
pileup modelling
Luminosity
JVT efficiency
2 1 0 1 2
(θ-θ0)/ θ
Flavour tagging
PCBT extrapolation unc. light mis-tag
PCBT extrapolation unc. c mis-tag
PCBT extrapolation unc. b-tag
bTag light-jets EV 9
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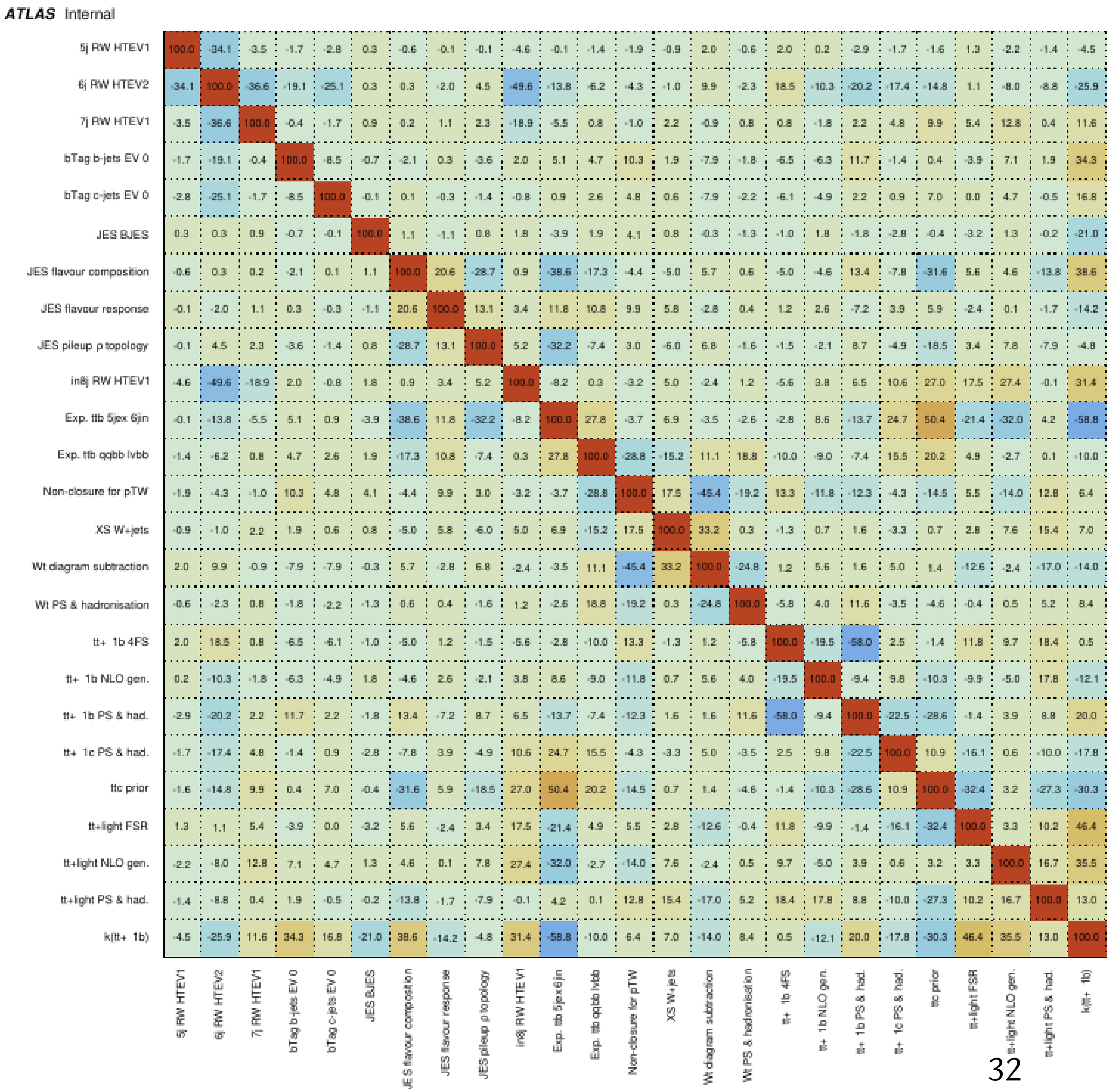
bTag b-jets EV 1
bTag b-jets EV 0
ATLAS Internal
ttbar_PDF
ttPDF_V9
ttPDF_V8
ttPDF_V7
ttPDF_V6
ttPDF_V5
ttPDF_V4
ttPDF_V30
ttPDF_V3
ttPDF_V29
ttPDF_V28
ttPDF_V27
ttPDF_V26
ttPDF_V25
ttPDF_V24
ttPDF_V23
ttPDF_V22
ttPDF_V21
ttPDF_V20
ttPDF_V2
ttPDF_V19
ttPDF_V18
ttPDF_V17
ttPDF_V16
ttPDF_V15
ttPDF_V14
ttPDF_V13
ttPDF_V12
ttPDF_V11
ttPDF_V10
ttPDF_V1
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
others
Non-closure for pTW
2 1 0 1 2
(θ-θ0)/ θ
ATLAS Internal
Theory
XS 4-tops
XS ttZ QCD
XS ttZ PDF
tt+Z Generator
XS ttW QCD
XS ttW PDF
tt+W Generator
ttH norm.
ttH PS & had.
ttH NLO gen.
t-chan PS & hadronisatio
XS tHjb QCD
XS tHjb PDF
XS single top (t-chan)
XS single top (Wt)
s-chan PS & hadronisatio
s-chan generator
XS Z+jets
Wt PS & hadronisation
Wt NLO
Wt diagram subtraction
XS tWH QCD
XS tWH PDF
XS W+jets
XS Diboson
2 1 0 1 2
(θ-θ0)/ θ

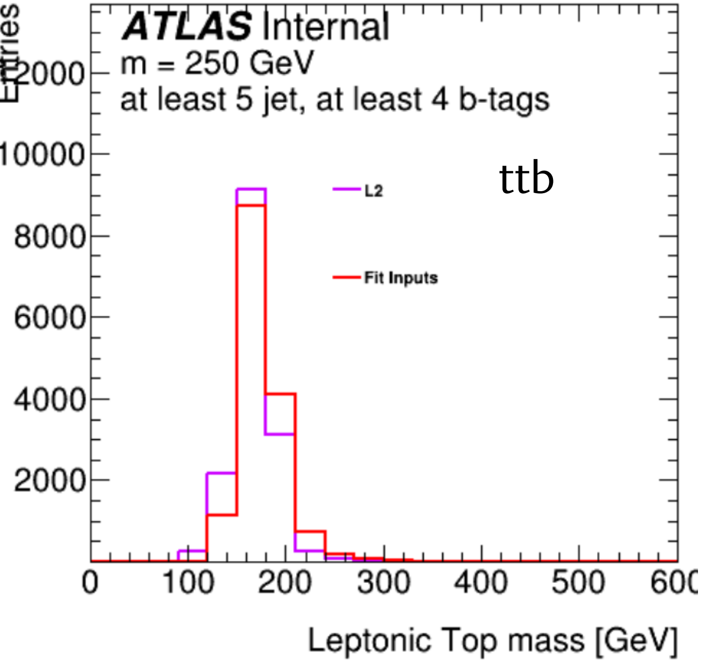
Correlation matrix

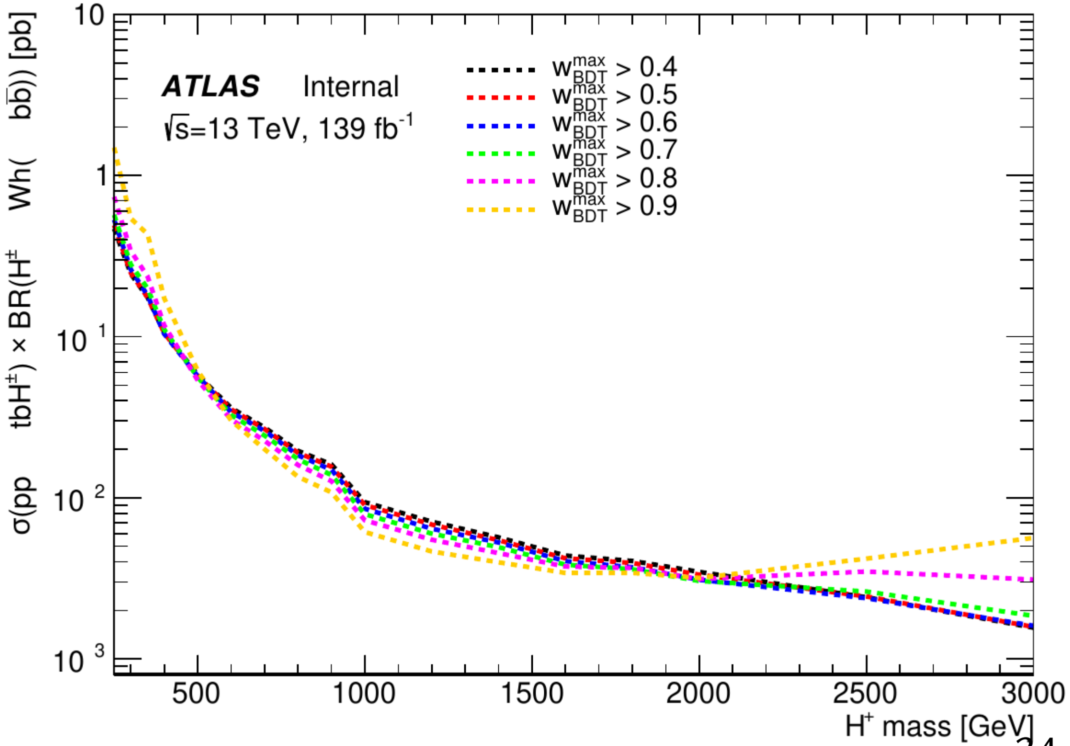


Adional slide on SR/CR deintion

Cross checks on the lvbb SR/CR definitions

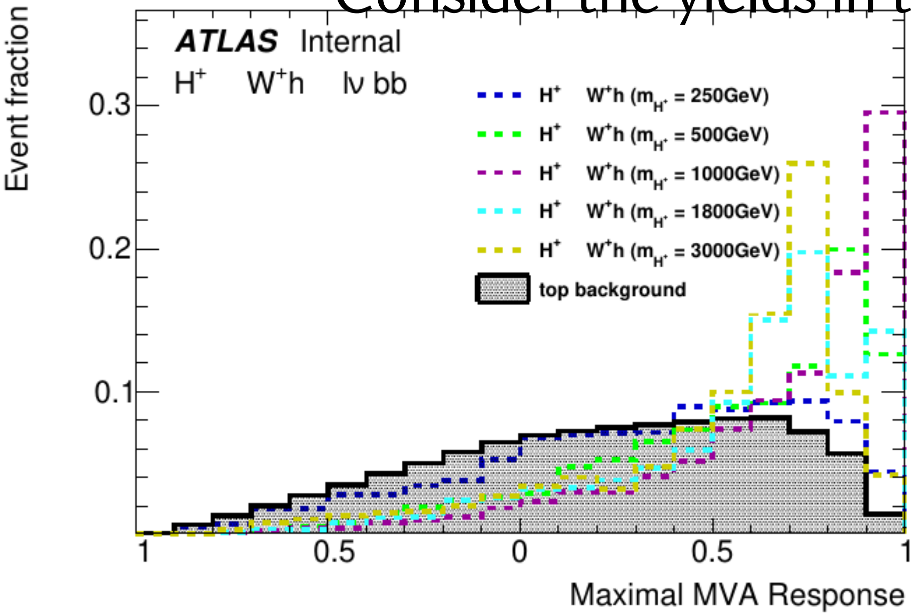
- Found a bug (basically missing parenthesis) in the calculation of top mass
  - The lvbb SRs and CRs were defined using this faulty code
  - Cross-check the definition of these region
  - Calculate stat only limits for different max MVA Response cuts
    - MaxMVA>0.7 still provides good limits in an intermediate mass range and better limits for high/low masses than stronger cuts
  - We will re-define the lvbb CRs for reasons not related to this bug

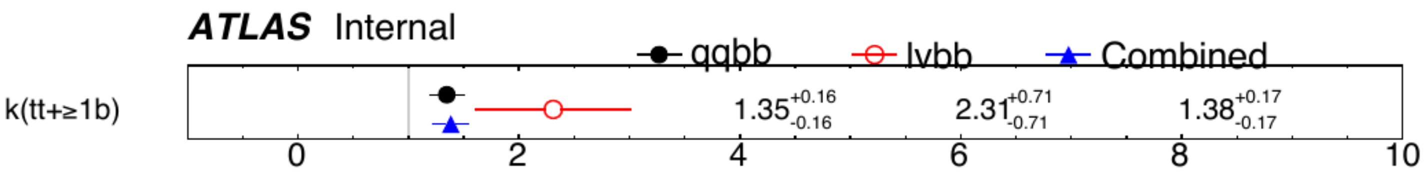




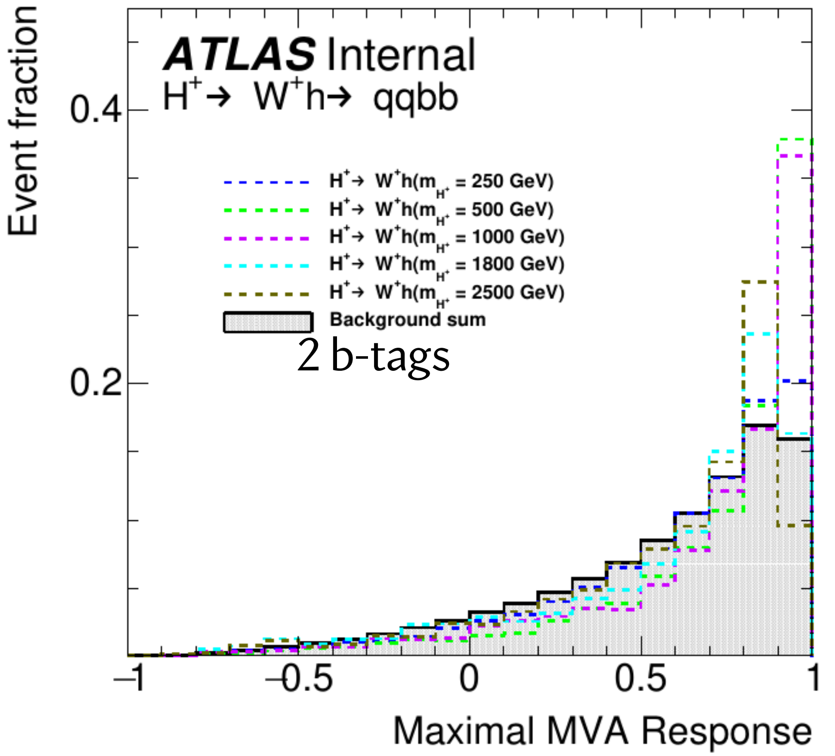
Re-definition of the lvbb control region

- Very low yields in current lvbb CRs (maxMVA< 0.0)
  - e.g 76 data events in the 4+ b lvbb CRs (with fixed code)
- Poor constraining power for tt+b
  - The normalization factor are way from those in the qqbb/comined fit
- Explore CRs defined by higher maxMVA cuts (up to 0.5)
  - Consider the yields in the definition of the CRs

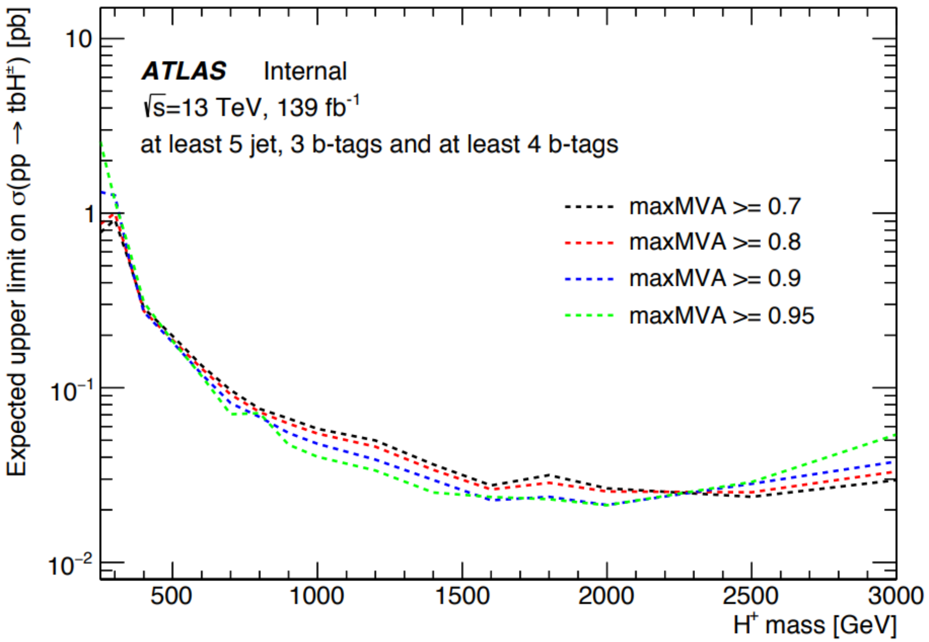


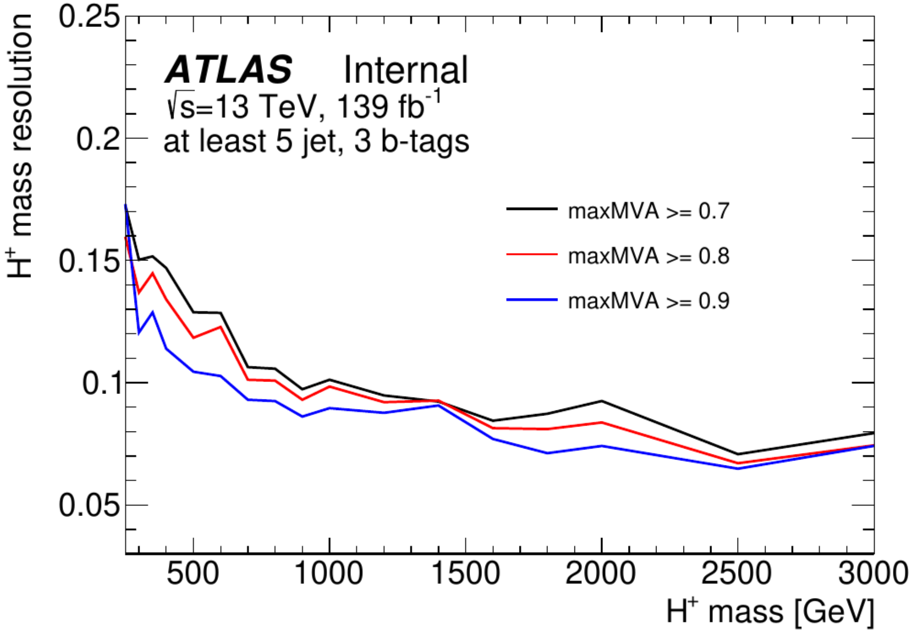


Definition of signal regions for $H^+ \to qqbb$



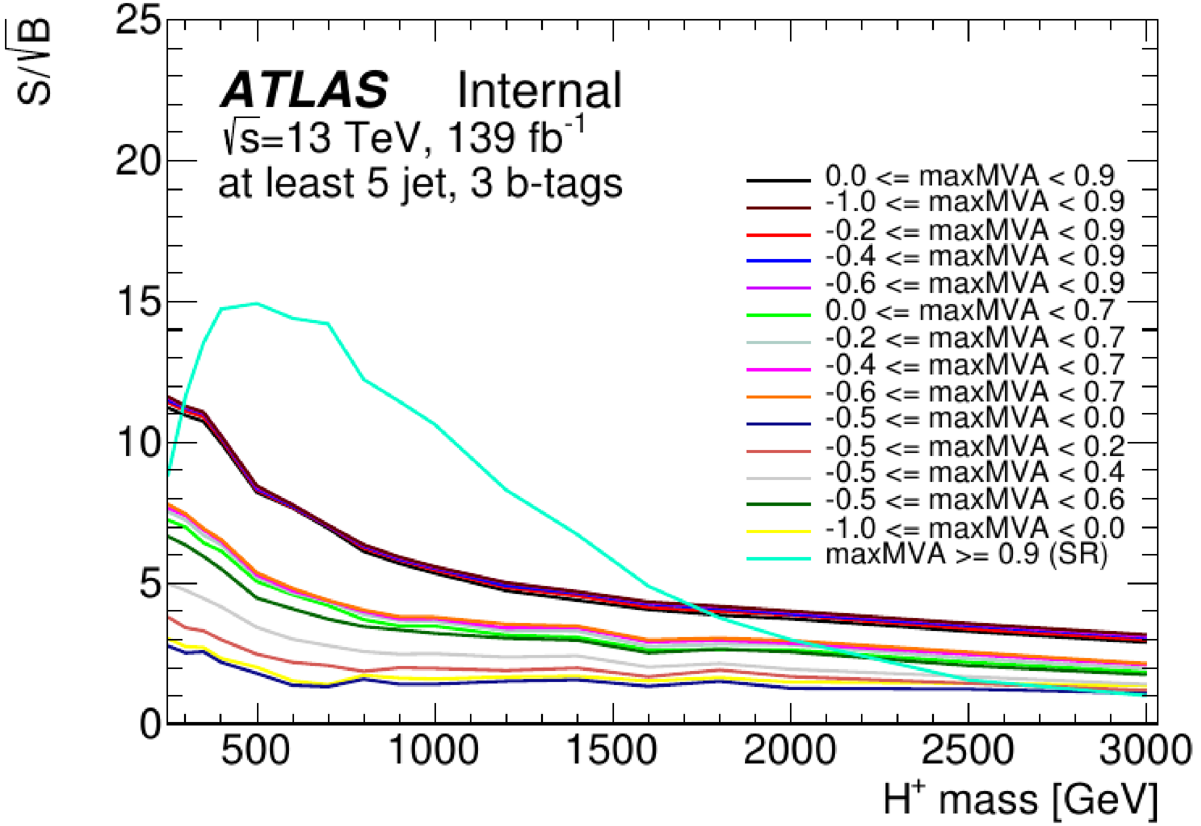
- Define SR in terms of the maxBDT score
  - Find a region enhanced in signal, depleted in background
- Calculate expected limits for each SR
- Check the mass Resolution
- Choose max MVA > 0.9 as SR to ensure sufficient statistics

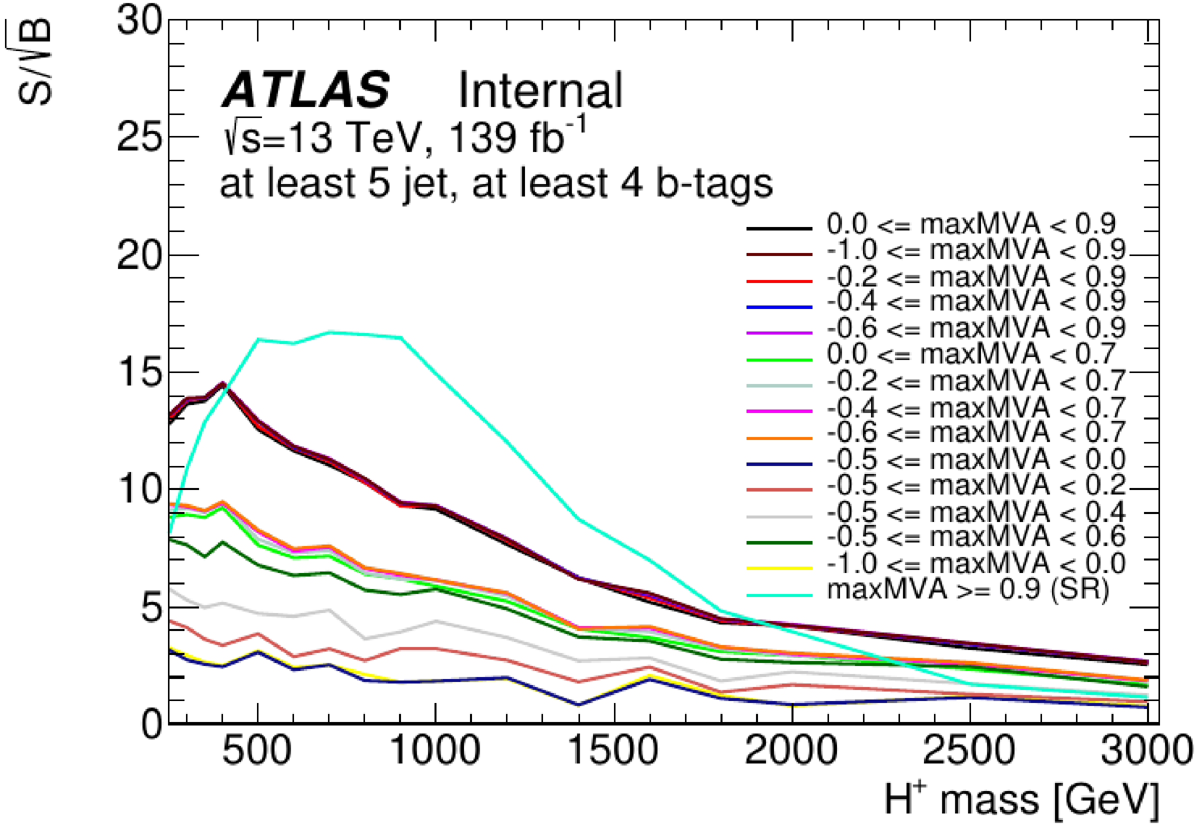




Definition of control regions for $H^+ \to qqbb$

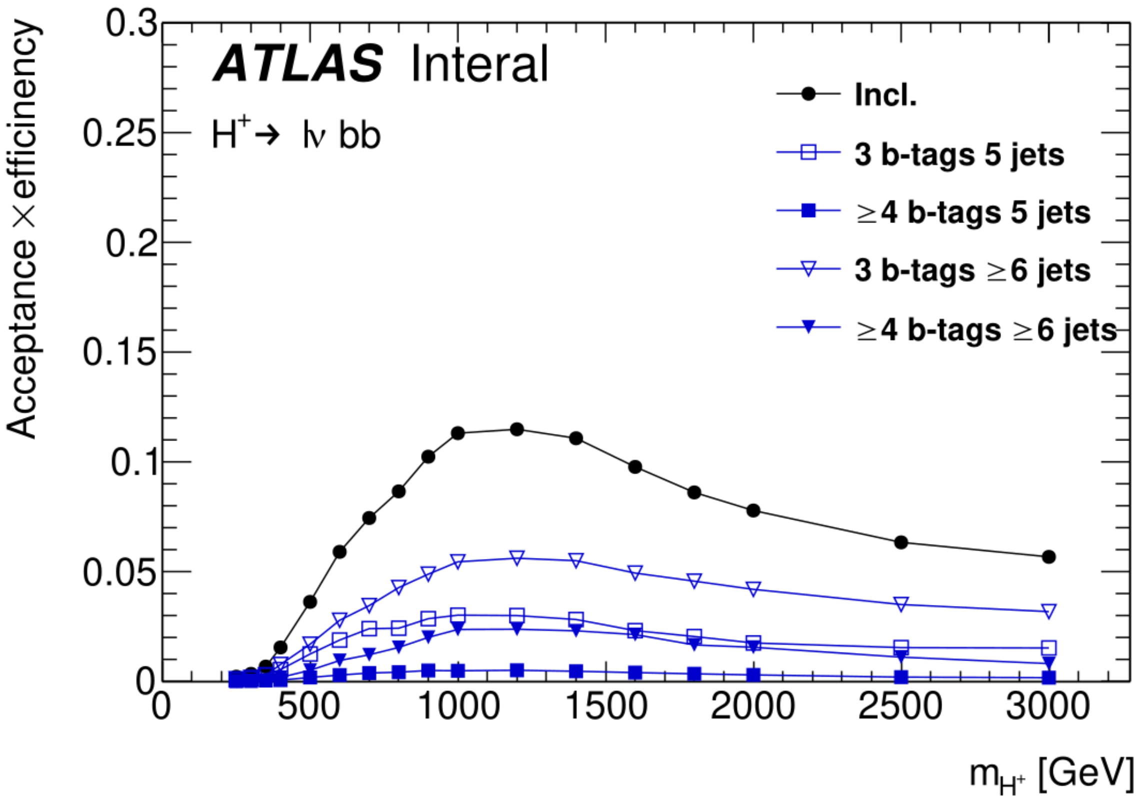
- Define the CR by an interval in BDT score
  - Find a region depleted in signal and enhanced in background
- Choose [-0.5,0](3b-tags) and [-0.5,0.6] (4+btags) as CRs

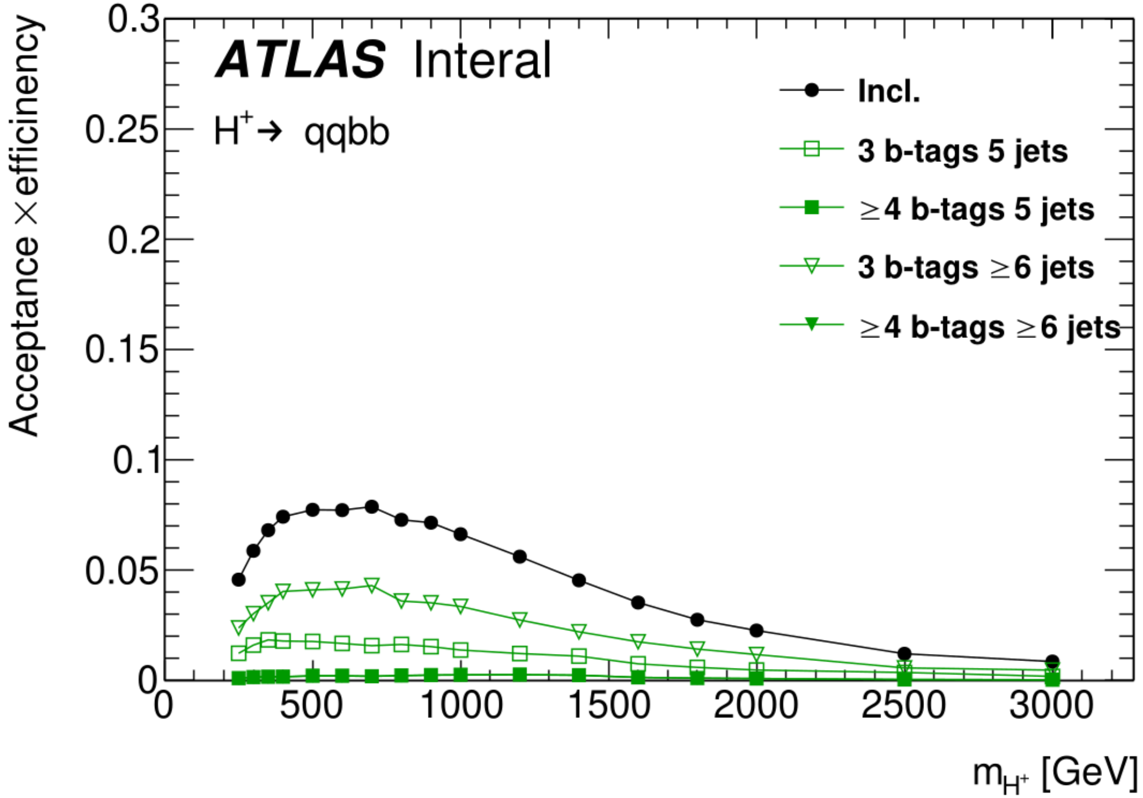




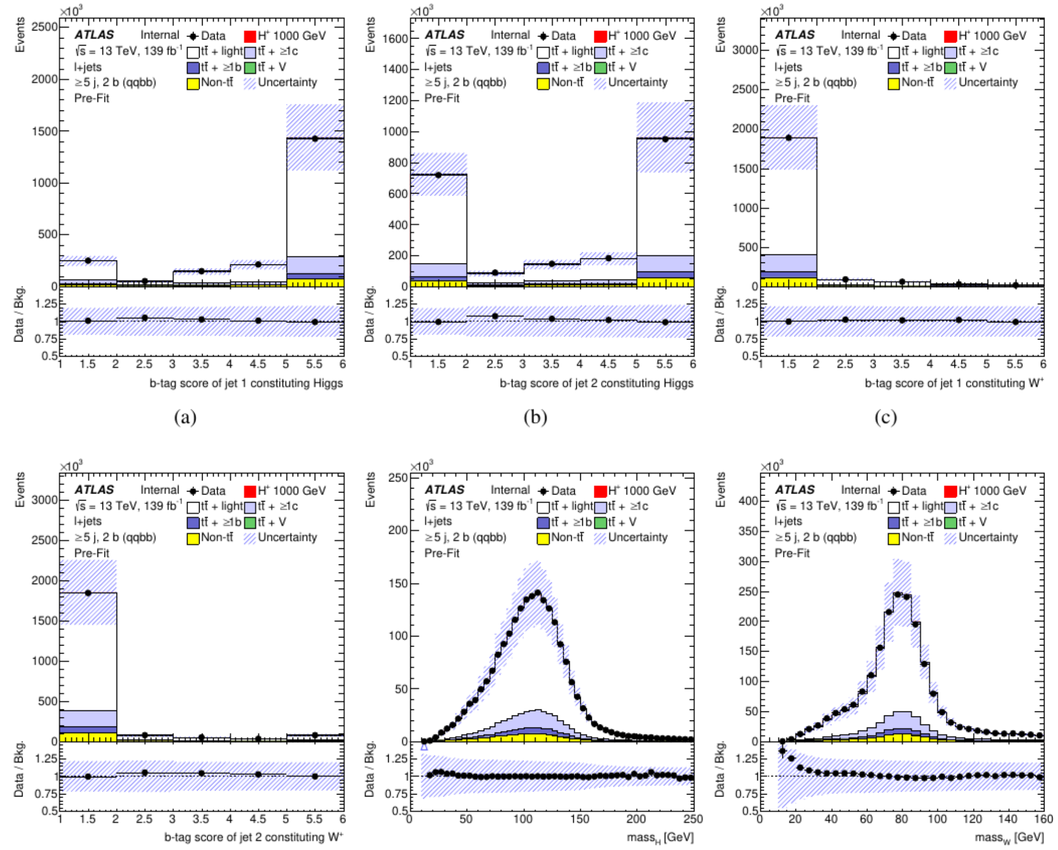
Acceptance x Efficiency

- The Signal and Control Regions are further split by the number of jets
  - 5 jet
  - 6 or more jets
  - This allow to better constrain the tt +bb, cc normalization



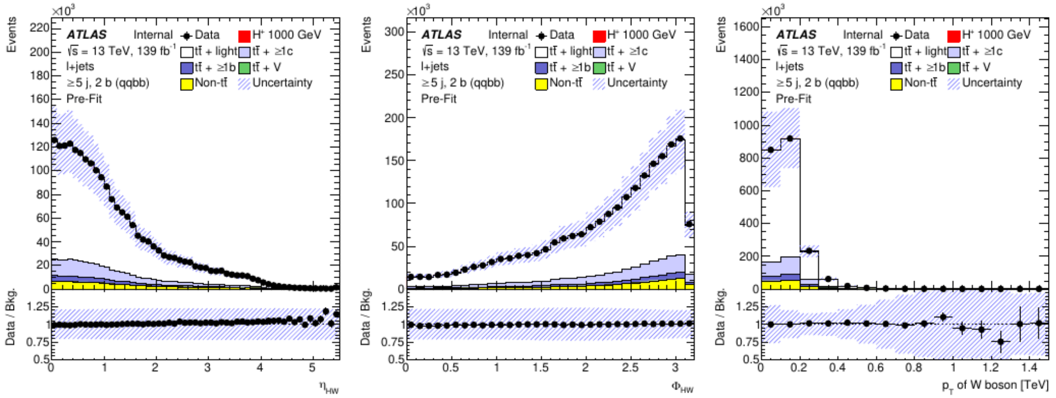


Data-MC Validation region (qqbb)

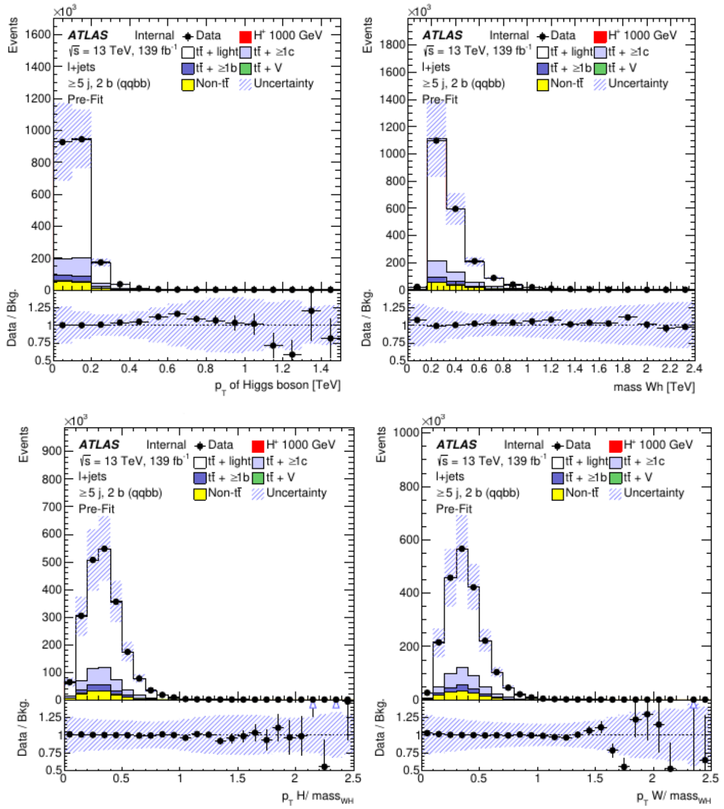


(a) (b) (c)

(d) (e) (f)

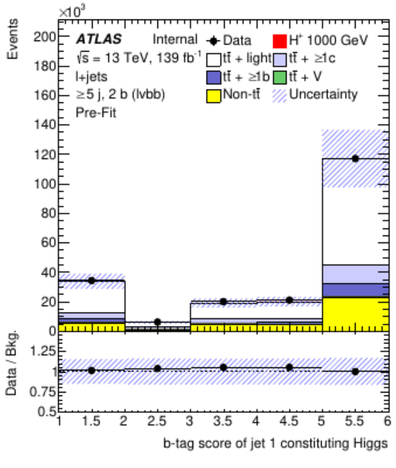


(a) (b) (c)

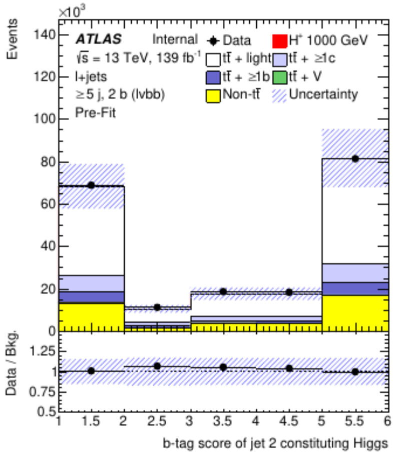


(g) (h)

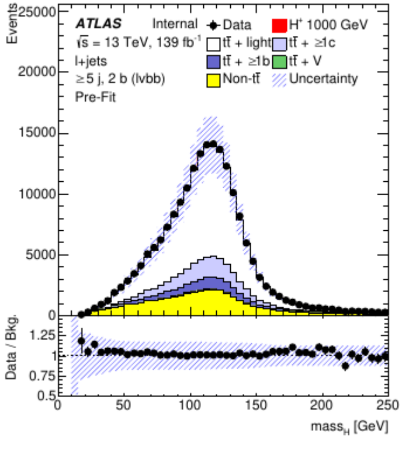
Data-MC Validation region (lvbb)



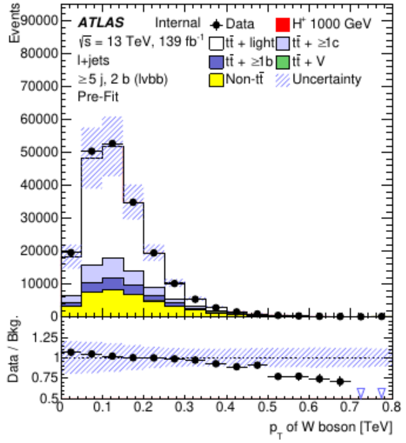
(a)



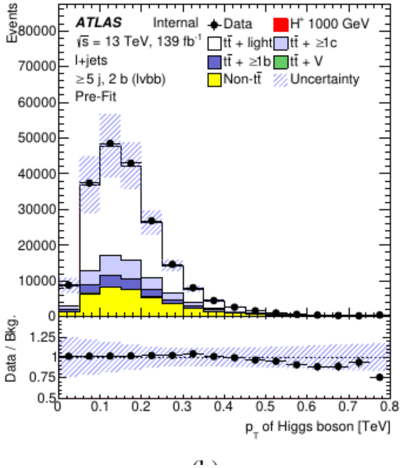
(b)

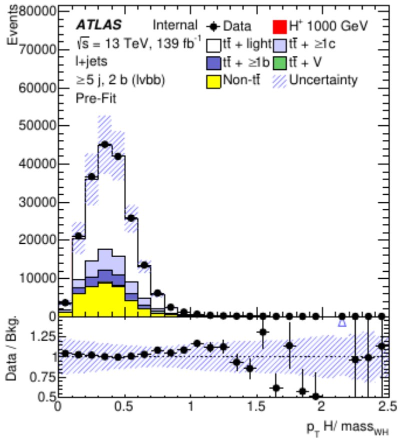


(c)

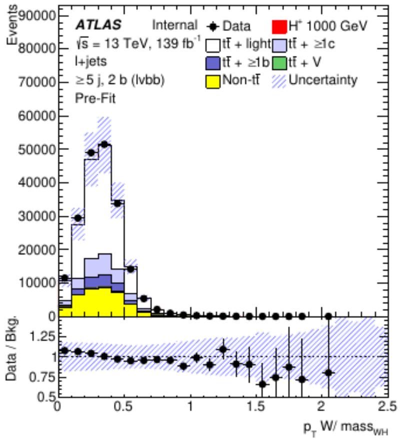


(a)





(d)



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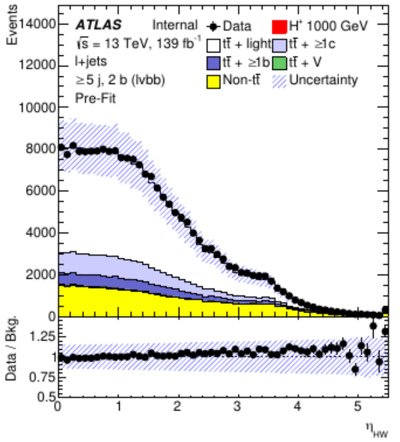

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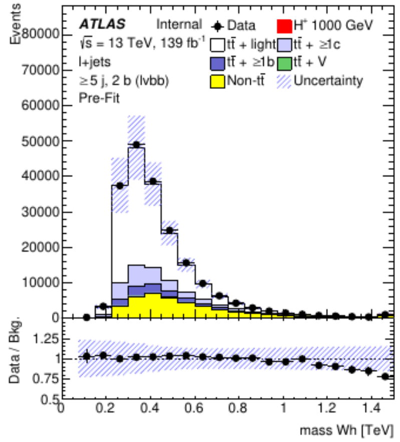

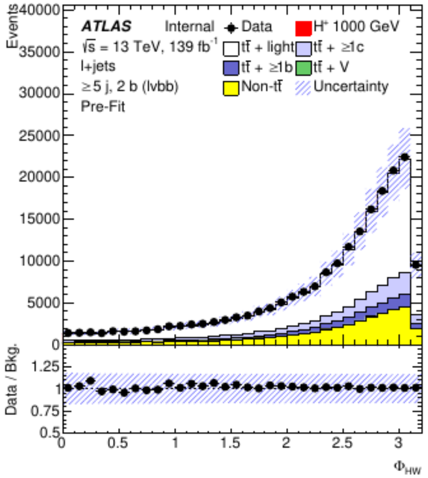

(c)