Search for heavy resonances decaying into a Z boson and a Higgs with llbb/vvbb final states with the ATLAS detector

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Conf note:
http://cdsweb.cern.ch/record/2728053

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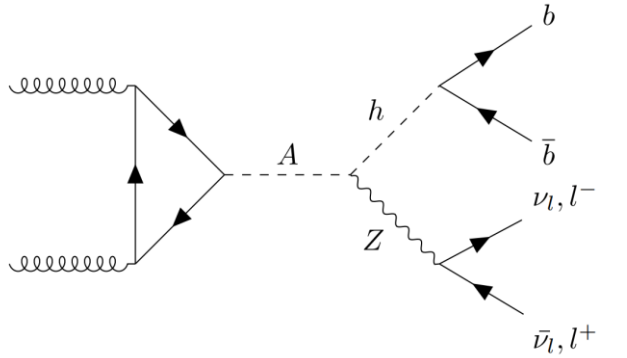
Targeted Signal Models

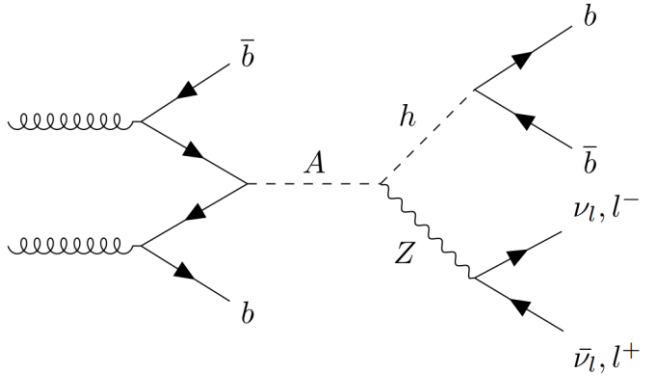
Two Higgs Doublet Model (2HDM)

- Various BSM theories require the existence of a second Higgs doublet
- 2HDM consists of 5 Higgs-like bosons: h, H, A and H±
- Consider CP-conserving 2HDM with mh = 125 GeV, mA=mH=mH±
- Two free parameters: mixing angle α, ratio of the vacuum expectation values of the two Higgs doublets β

2HDM A gluon fusion production



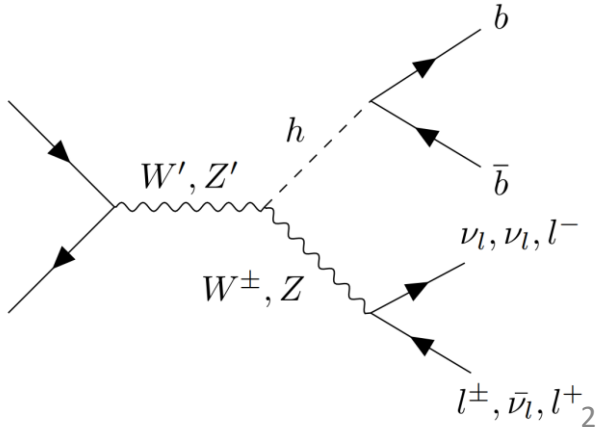
2HDM A b-associated production



Heavy Vector Triplets (HVT)

- Various BSM theories predict a new strong interaction at a higher energy scale
- Heavy new gauge bosons: Z’ and W’

HVT Drell-Yan production



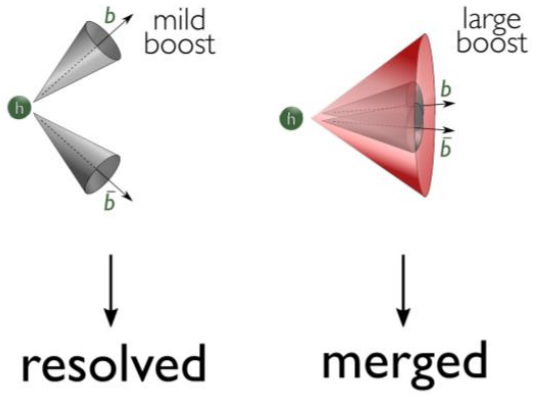
Analysis Strategy

2 channels depending the Z decay

- 0 lepton channel
- 2 lepton channel

2 regimes depending on h reconstruction

- Resolved: 2 small-R (0.4) calo jets
- Merged: 1 large-R (1) calo jets



b-tagging

- Use the 70% efficient b-tagging WP
- Select resolved events with at least 1 b-tagged small-R jet
- Or merged events with at least 1 b-tagged track jet associated with the large-R jet

Priority resolved

- Event categorized as resolved if it satisfies both the resolved and the merged SR event selection

Event Selection and Fit Strategy

Signal regions

- Events with mbb inside the Higgs mass window
- Also satisfy other selections on lepton and jet pt, missing transverse energy and mll to enhance signals
- Main background: Z+jets, W+jets, top

mbb sideband control region

- Events with mbb not inside the Higgs mass window
- Dominated by Z+jets, W+jets, top background

Top control region in 2L

- Events with different flavour leptons
- Revert cut on missing transverse energy
- Dominated by top background

Fit Strategy

- ggA/HVT fits use 1, 2 tagged resolved events and merged events with no additional b-tagged jets
- bbA fit also uses 3+ tagged resolved events and merged events with additional b-tagged jets
- In the bbA fit:
  - The ttbar background are splitted into ttbar+HF and ttbar+LF
  - 3+ b-tagged Z+jets background are modelled separately from 1, 2 b-tagged Z+jets

Signal and Background Modelling

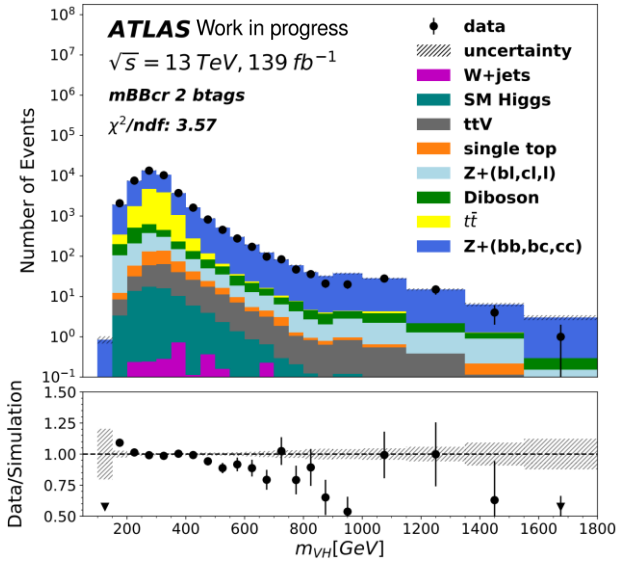
Shape and normalization

- All signals are modelled by MC
- The shapes of all background are modelled by MC
- The normalizations of the three main background (ttbar, Z+jets and W+jets) are determined from the fit
- The normalizations of other small backgrounds (diboson, SM Higgs) constrained to SM predictions

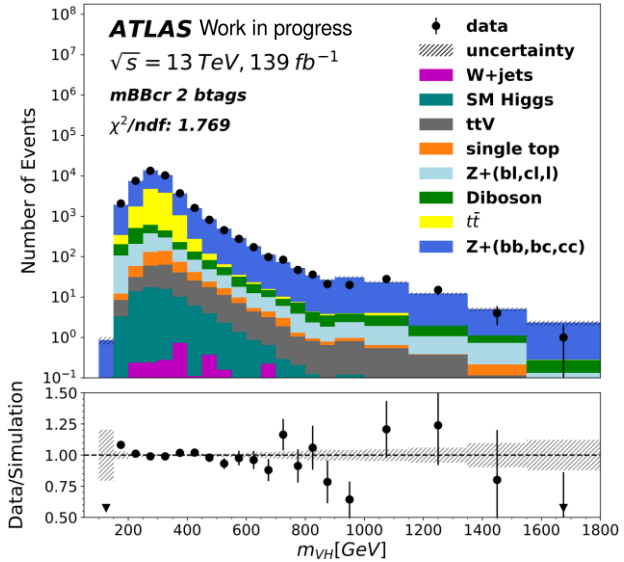
Data-driven correction

- The background events in the signal regions are reweighted to improve the modelling
- Reweighting functions are derived from the mbb sideband control regions
- Reweighting is based on ptbb, large-R jet pt and missing transverse energy

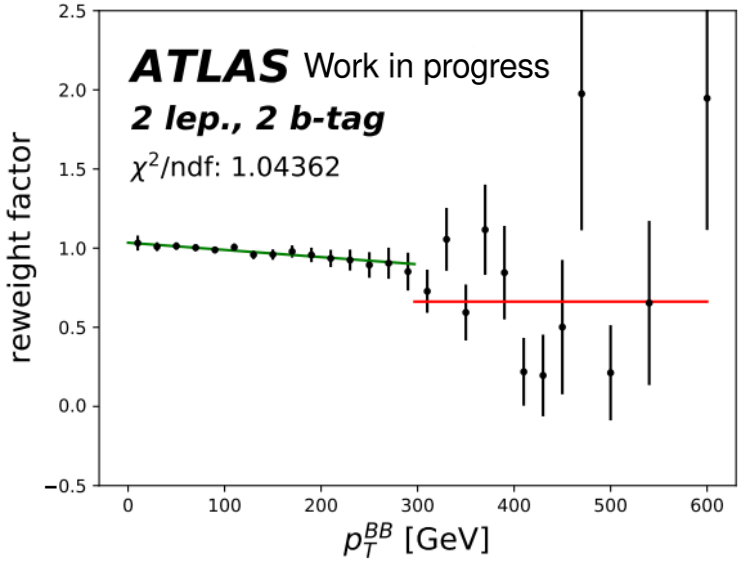
Before correction



After correction



Reweighting function

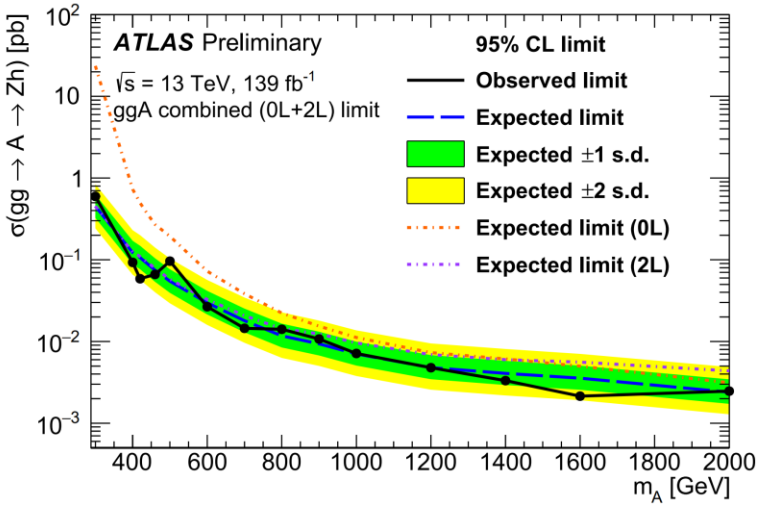


Limits

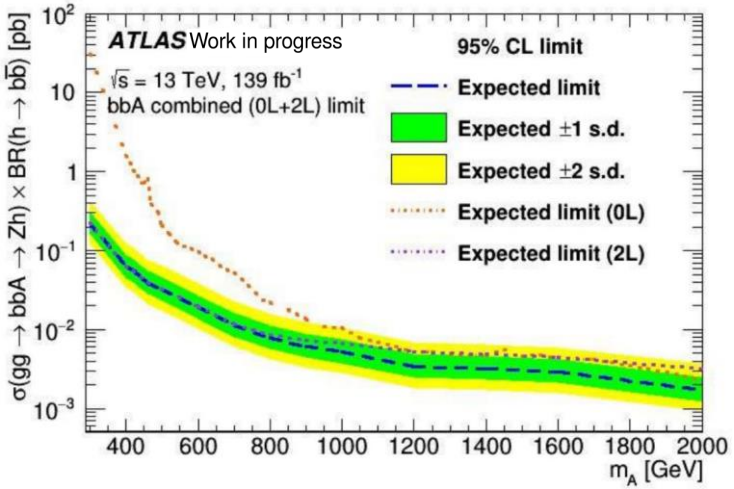
Asymptotic limits

ggA

Plot taken from Conf note

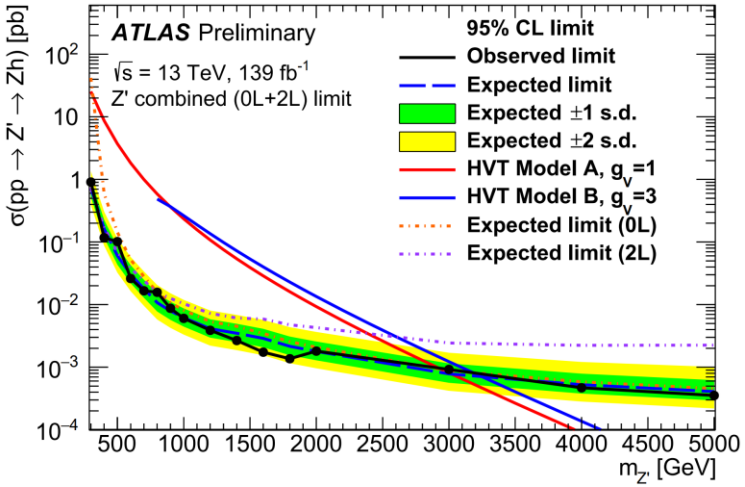


bbA



Z’

Plot taken from Conf note

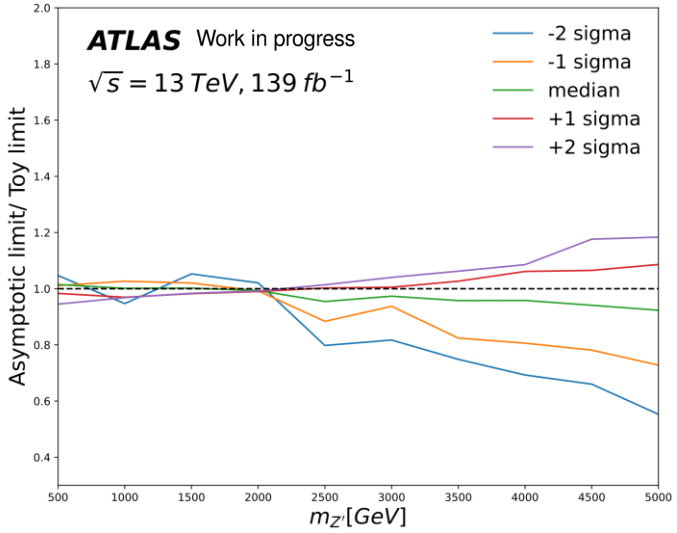


- ggA/Z’ observed limits agree well with the SM prediction

Toy limits

- Z’ search goes up to 5000 GeV
- Asymptotic formula fails at high mass due to the low number of events
- 7% difference between the toy median limit and asymptotic median limit at 5000 GeV

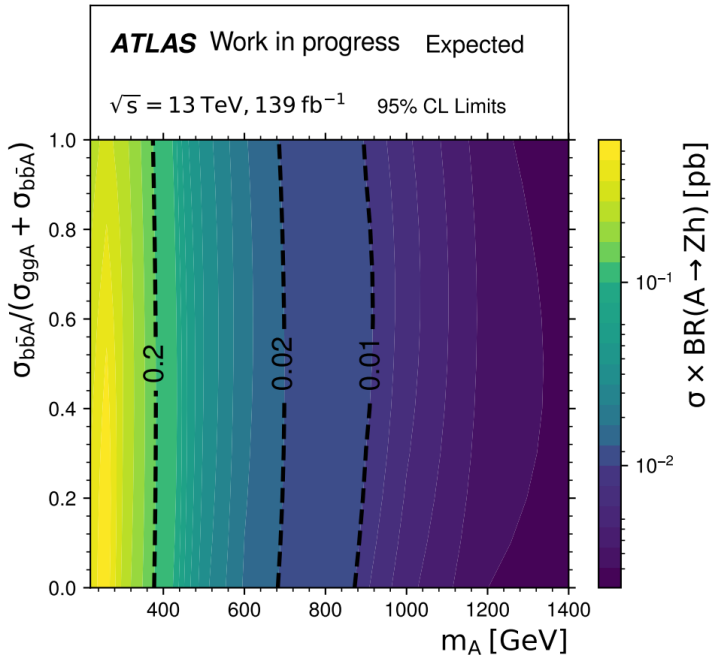
Asymptotic vs toy



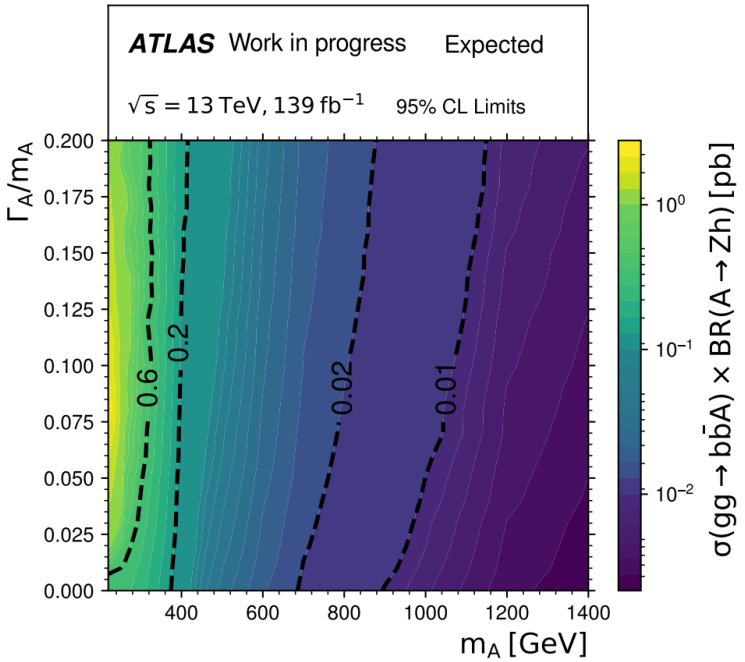
2HDM Interpretation

- A boson width and bbA/ggA fraction vary strongly as a function of the mass, tan beta and cos(beta - alpha)
- Signal samples generated with Narrow Width approximation
- NWA distribution smeared to create large width distribution
- bbA signal and ggA signal mixed with different ratio
- Calculate limits in the 3D grid of ggA/bbA fraction, signal width and signal mass

Limits in the fraction/mass space



Limits in the width/mass space

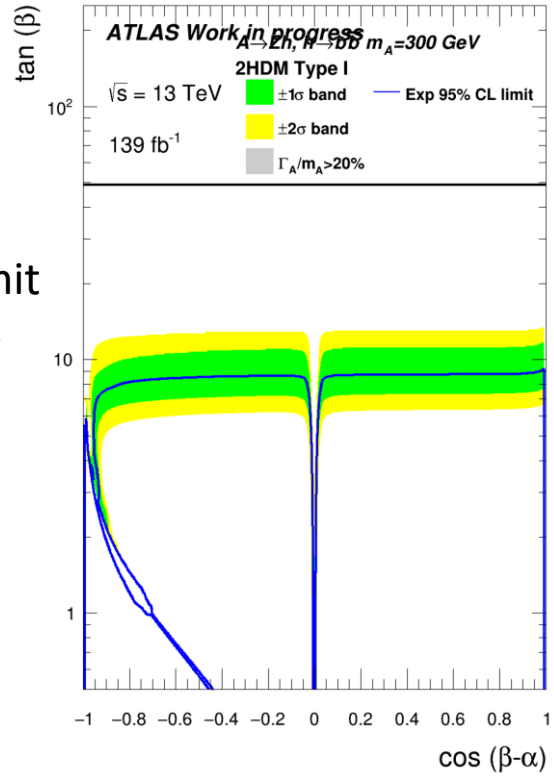


2HDM Interpretation

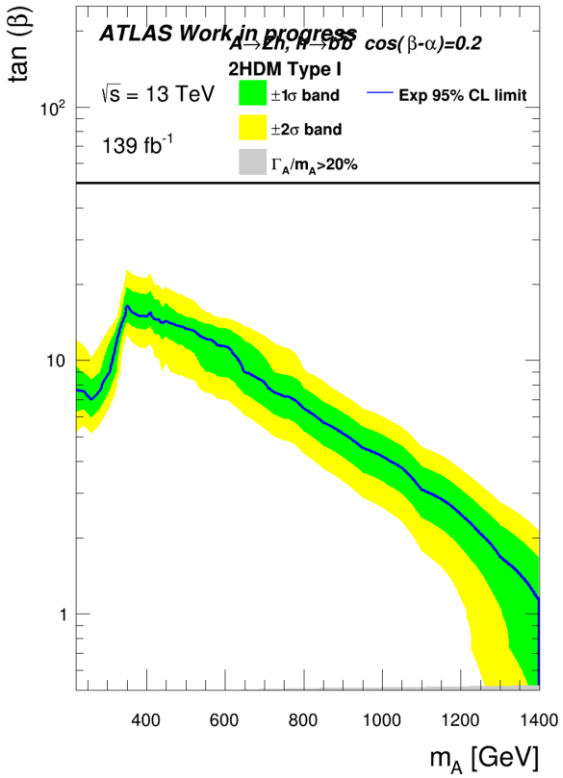
- 4 types of 2HDM models depending how fermions interact with the Higgs Doublets: Type I, Type II, flipped, lepton specific
- 3 parameters: mA, tanb, cos(b-a)
- The theory cross-sections were calculated using up to next-to-next-to-leading-order (NNLO) QCD corrections with 5FS implemented in SUSHI

Examples

- Expected limit on tanb/cos(b-a) space
- Type-I model
- Gap in the middle: alignment limit where the A coupling to Zh goes zero
- Gap on the left: h>bb decay not possible



- Expected limit on tanb/mA space
- Type-I model
- A production decreases as tanb increases



Conclusion

- Searched for Z’ and A using the full run2 ATLAS data corresponding to a total integrated luminosity of 139 fb−1
- Upper Limits on XS placed in the mass range of 300 GeV to 5 TeV for Z’ and 220 GeV to 2 TeV for ggA/bbA
- No significant excess found for ggA/Z’
- Upper limits will be also placed on the 2HDM model and HVT model parameter space

Backup

Signal and background samples

Process	Generator	Prediction order of σ_{prod}
$W \to \ell\nu, Z \to \ell\ell, Z \to \nu\nu$	Sherpa 2.2.1	NNLO
$t\bar{t}$	Powheg + Pythia8	NNLO+NNLL
single top ($s/t/Wt$-channel)	Powheg + Pythia8	NLO
$t\bar{t} + h$	MG5_aMC@NLO + Pythia8	NLO (QCD) and NLO (EW)
$t\bar{t} + V$	MG5_aMC@NLO + Pythia8	NLO
$qg/q\bar{q} \to VV \to \ell\ell/\ell\nu/\nu\nu + q\bar{q}$	Sherpa 2.2.1	NLO
$gg \to VV \to \ell\ell/\ell\nu/\nu\nu + q\bar{q}$	Sherpa 2.2.2	NLO
$qg/q\bar{q} \to \ell\ell\nu\nu$	Sherpa 2.2.2	NLO
$qq \to Wh \to \ell\nu + b\bar{b}$	Powheg + Pythia8	NNLO (QCD) and NLO (EW)
$qq \to Zh \to \ell\ell/\nu\nu + b\bar{b}$	Powheg + Pythia8	NNLO (QCD) and NLO (EW)
$gg \to Zh \to \ell\ell/\nu\nu + b\bar{b}$	Powheg + Pythia8	NLO+NLL

Table taken from Conf note

Event selection

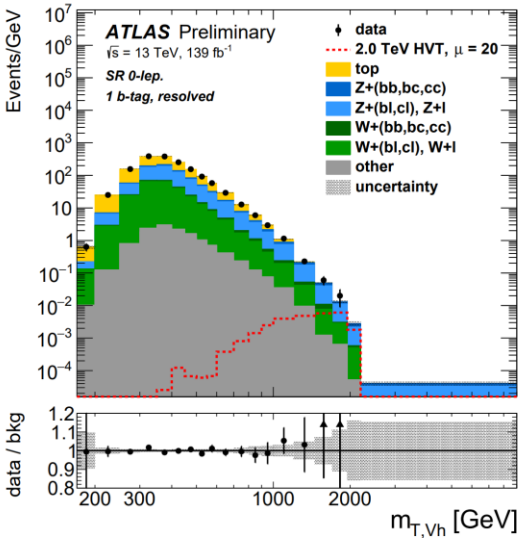
Variable	Resolved	Merged
	Common selection	
Number of jets	≥2 small-R jets (0, 2-lep.) 2 or 3 small-R jets (1-lep.)	≥1 large-R jet ≥ 1 VR track-jets (matched to leading large-R jet)[‡‡]
Leading jet p_{T} [GeV]	> 45	> 250
m_h [GeV]	110–140 (0,1-lep.), 100–145 (2-lep.)	75–145
	0-lepton selection	
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 200
S_{T} [GeV]	> 150 (120[*])	–
$\Delta\phi_{jj}$	$< 7\pi/9$	–
$p_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 60	
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	$< \pi/2$	
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, h)$	$> 2\pi/3$	
$\min\left[\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \text{small-}R\text{ jet})\right]$	$> \pi/9$ (2 or 3 jets), $> \pi/6$ (≥ 4 jets)	
$N_{\tau_{\mathrm{had}}}$	0[**]	
MET significance $\mathcal{S}$	$\begin{cases} > 9 & \text{if } m_{Vh} < 240\,\text{GeV}, \\ > 6.6 + 0.01 \cdot m_{Vh} & \text{if } 240\,\text{GeV} \leq m_{Vh} < 700\,\text{GeV}, \\ > 13.6 & \text{if } m_{Vh} > 700\,\text{GeV}, \end{cases}$	
	2-lepton selection	
Leading lepton p_{T} [GeV]	> 27	> 27
Sub-leading lepton p_{T} [GeV]	> 20	> 25
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [$\sqrt{\text{GeV}}$]	$< 1.15 + 8 \times 10^{-3} \cdot m_{Vh}/(1\,\text{GeV})$	
$p_{\mathrm{T},\ell\ell}$ [GeV]	$> 20 + 9 \cdot \sqrt{m_{Vh}/(1\,\text{GeV}) - 320}$[††]	
$m_{\ell\ell}$ [GeV]	$\left[\max\left[40\,,\ 87 - 0.030 \cdot m_{Vh}/(1\,\text{GeV})\right], 97 + 0.013 \cdot m_{Vh}/(1\,\text{GeV})\right]$	
$\Delta R(\ell, h)$	> 2.0	

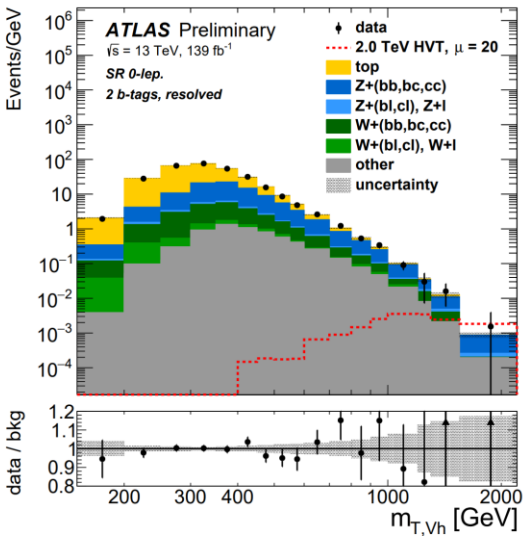
Table taken from Conf note

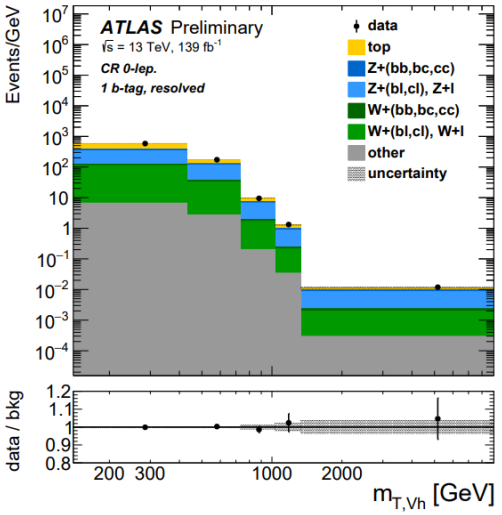
0 lepton channel post-fit distributions

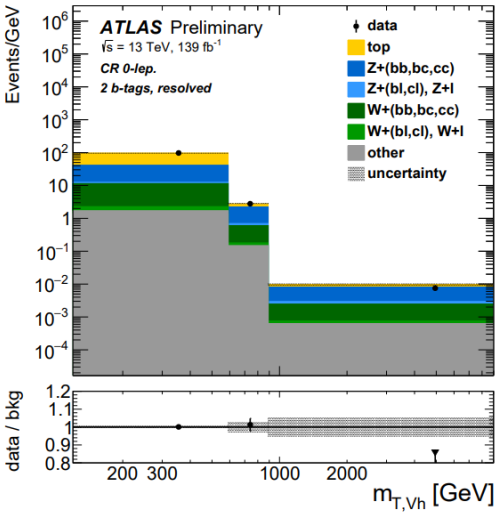
1 tag | **2 tag** | **Control regions**

Resolved

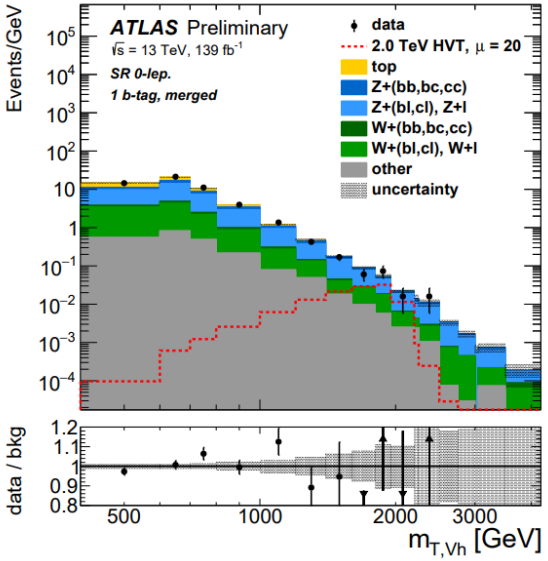


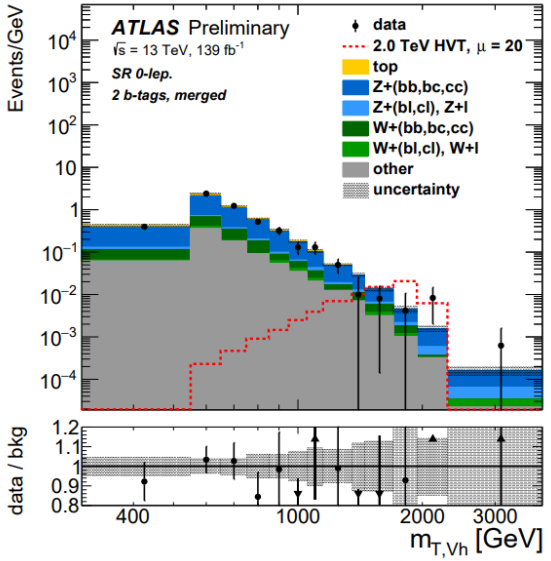






Merged





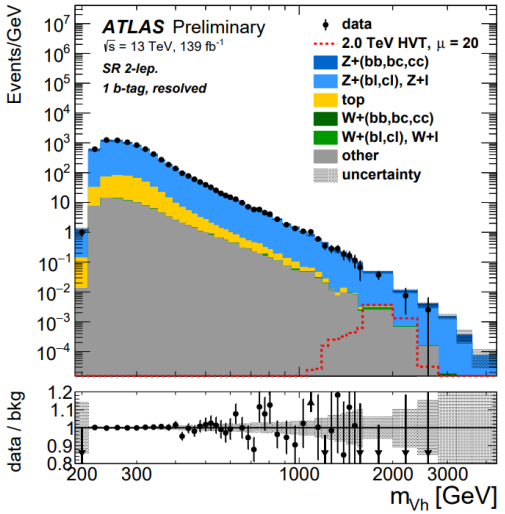
All plots taken from Conf note

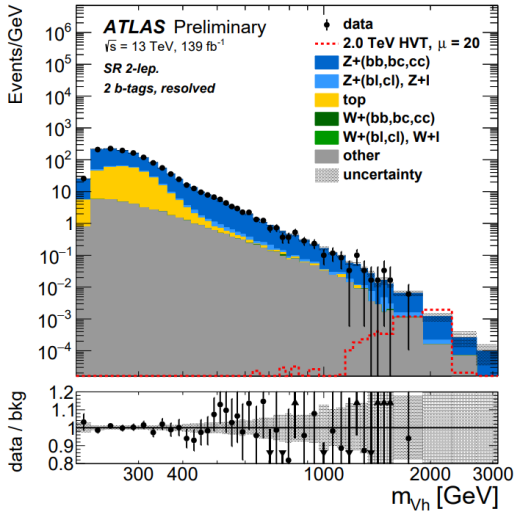
- Good data/mc agreement

2 lepton channel post-fit distributions

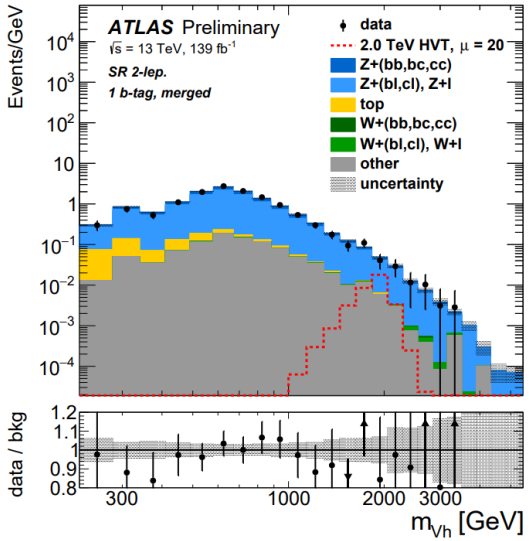
1 tag | **2 tag**

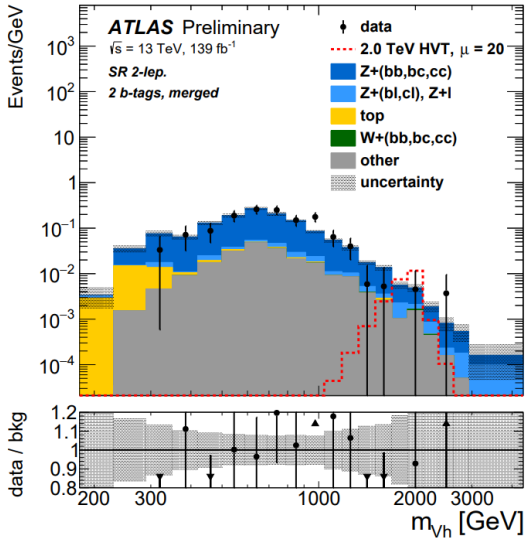
Resolved





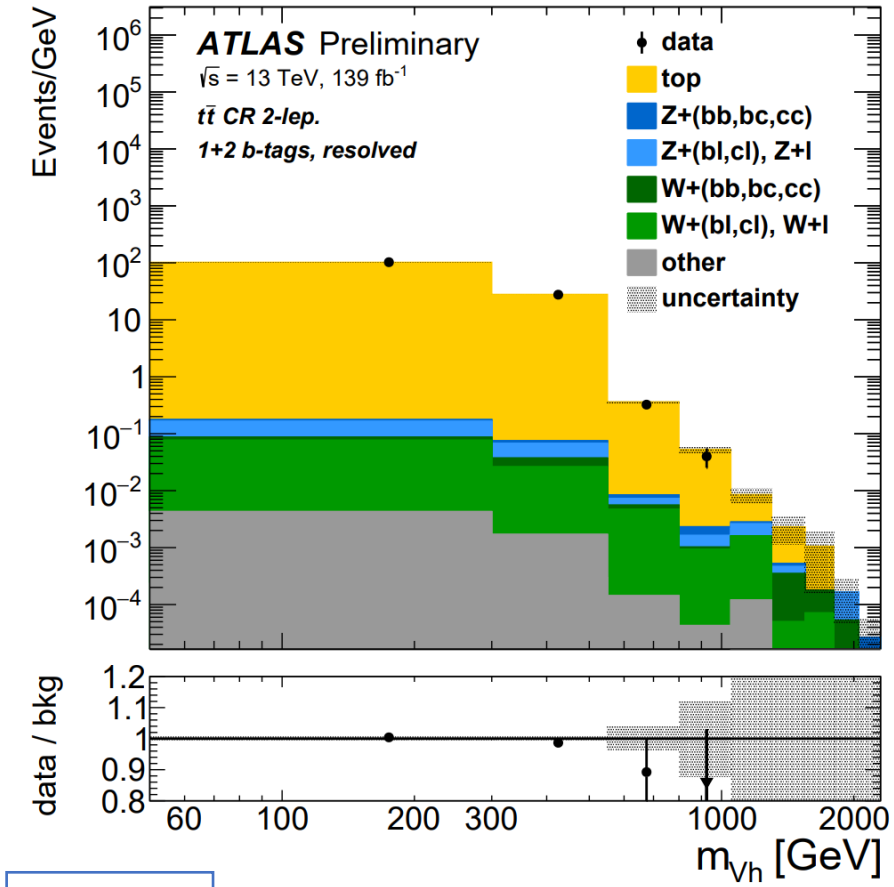
Merged





- Good data/mc agreement

Top CR



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