

$$A \rightarrow ZH \rightarrow llbb$$

Carl Gwilliam, Helen Hayward, Andy Mehta, Paul Thompson



UNIVERSITY OF
LIVERPOOL

(on behalf of Liverpool/Birmingham group)



12th November 2013
HH Meeting

Outline



- 1 Introduction
- 2 Selection
- 3 Control Plots
- 4 Backgrounds
- 5 $H \rightarrow ZZ \rightarrow llqq$ Results (Blinded)
- 6 $A \rightarrow ZH \rightarrow llbb$ Results (Blinded)



1 Introduction

2 Selection

3 Control Plots

4 Backgrounds

5 $H \rightarrow ZZ \rightarrow llqq$ Results (Blinded)

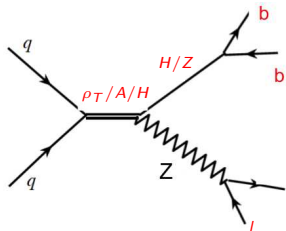
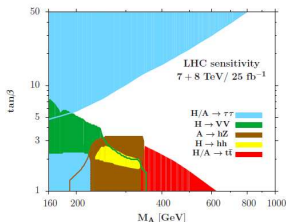
6 $A \rightarrow ZH \rightarrow llbb$ Results (Blinded)

Introduction

- Liverpool/Birmingham heavily involved in many $llbb$ final states:
 - $SM\ ZH, H \rightarrow bb$ (HSG5)
 - Timescale: finalise analysis asap with paper before Moriond
 - $High\ mass\ H \rightarrow ZZ \rightarrow llqq$ (HSG2)
 - 2HDM + EW singlet interpretation
 - Timescale: finalise by end '13 with common $H \rightarrow ZZ$ paper spring '14
 - $MWT\ \rho_{TC} \rightarrow Z\pi_{TC} \rightarrow llbb$ where $m(\pi_{TC}) = 126\text{ GeV}$ (Exotics)
 - Exactly same as $A \rightarrow ZH$ expect for interpretation
 - Timescale: finalise by end '13 with paper spring '14
- Analyses based as closely as possible on HSG5 recommendations with resonance optimisation from HSG2 high mass analysis
 - Stick as close as possible to HSG5 selection
 - Similar “flavour fit” method co normalise backgrounds
 - Same MC samples
 - Coherent systematic procedures
- Plan to use knowledge of this final state to work on $A \rightarrow ZH \rightarrow llbb \dots$

2HDM Analyses

- $H \rightarrow ZZ \rightarrow llqq$ well advanced within HSG2
 - Interpretation coordinated by HSG6 \rightarrow coherent approach + benchmarks
 - Typel/II 2HDM with $\sin(\beta - \alpha) \sim 1$ and scan over m_H and $\tan(\beta)$
 - Current strategy to use SM samples and scale σ following HSG6 twiki
- $H \rightarrow ZZ \rightarrow vvbb$ effort also starting within HSG2 (Sinica)
 - Plan to add in later at timescale of combined 2HDM paper
- $A \rightarrow ZH \rightarrow llbb$ ramping up quickly based on experience above
 - No $A \rightarrow ZH$ signal as yet \rightarrow use MWT scaled to σ from above twiki
- Only difference between $A \rightarrow ZH$ and $H \rightarrow ZZ$ in $llbb$ FS is m_{jj} cut



Datasets

- Muon/Egamma streams: 20.3 fb^{-1} @ $\sqrt{s} = 8 \text{ TeV}$
- Background MC:
 - Z/W +jets: Inclusive + boosted Sherpa $l/c/b$ samples
 - Combined as on [HSG5 twiki](#)
 - k-factor of 1.12 (Z) and 1.10 (W)
 - $t\bar{t}$: Powheg samples
 - Single top: Powheg (Wt/s -chan) /Acer (t -chan) samples
 - Diboson ($ZZ/WZ/WW$): Herwig samples
 - Unfiltered WW/WZ samples
 - ZZ lepton filter/MET veto + MET filter/lepton veto
 - QCD Multijet from data (looser lepton ID + reversed track isolation)



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Lepton Selection

- Author 1 or 3 GSF electrons
- **VeryLooseLH**
- loose: $p_T > 7 \text{ GeV}$
- signal: $p_T > 25 \text{ GeV}$
- $|\eta_{\text{clus}}| < 2.4$
- OQ
- $\sum p_T(\Delta R = 0.2)/p_T < 0.10$
- $|d_0| < 0.1 \text{ mm}$; No $|z_0|$ cut
- Trigger matching
- Recommended CP corrections for both elec/muon
- MUID Muons
- Tight CB/ST $|\eta| < 2.7$
- SA $2.5 < |\eta| < 2.7$
- Calo $|\eta| < 0.1$
 - CaloMuonIDTag > 10 || CaloLRLikelihood > 0.9
 - Reject if $\Delta R < 0.1$ to CB/ST
- loose: $p_T > 7 \text{ GeV}$ (20 if Calo)
- signal: CB/ST $p_T > 25; |\eta| < 2.5$
- ID/MS hit requirements
- $\sum p_T(\Delta R = 0.2)/p_T < 0.10$ (not SA)
- $|d_0| < 0.1 \text{ mm}$ (not SA)
- $|z_0| < 10 \text{ mm}$ (not SA)

Jet Selection + Overlap Removal

- Anti- k_t 4 jets with:
 - Signal jets: $p_T > 20 \text{ GeV}$ & $|\eta| < 2.5$
 - Veto jets: + $p_T > 30 \text{ GeV}$ & $2.5 < |\eta| < 4.5$
- $|JVF| > 0.5$
 - $|\eta| < 2.4; p_T < 50 \text{ GeV}$
- BadLooser cleaning + Hot Tile cell veto
- b -tagging using MV1c @ 70%
- Recommended CP corrections

- Overlap removal:
 - Remove jets within $\Delta R = 0.4$ of loose elec
 - Remove loose muons with $p_T < 20 \text{ GeV}$ within $\Delta R = 0.4$ of jet
 - Significantly improves signal acceptance with similar background level
 - Remove loose elec within $\Delta R = 0.2$ of loose muon, except for calo muons where keep elec

Event Selection

Based on HSG5 selection at VHbbBaseLinePublication

- Preselection + recommended single/dilepton triggers
- One loose + 1 signal same-flavour lepton
 - Opposite charge only from muons
 - 1/2 leptons must be trigger matched for single/di-lepton trigger
- No additional loose lepton
- $83 < m_{ll} < 99$ GeV
- $MET_RefFinal < 60$ GeV
- ≥ 2 jets
- Exclusive 0/1/2 b tag categories using MV1c at 70%
 - 2-tag: 2 highest b -weight jets (signal)
 - 1-tag: highest b -weight + p_T (control)
 - 0-tag: two highest p_T jets (control)
- No ΔR_{jj} cut
- $A \rightarrow ZH : |m_{jj} - m_h| < 20$ GeV; $H \rightarrow ZZ : 70 < m_{jj} < 105$ GeV
- Optimised $H \rightarrow ZZ \rightarrow llqq$ cuts as function of reconstructed m_{llqq}
 - $P_T^{jet} > 0.1 m_{llqq}$, $p_T^l > -77.54 + 0.47 m_{llqq}$, $\Delta\phi_{ll} > 3.2 \times 10^8 / m_{llqq}^{3.5} + 1$



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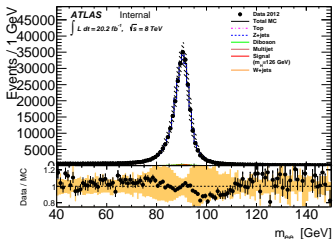
4 Backgrounds

5 $H \rightarrow ZZ \rightarrow llqq$ Results (Blinded)

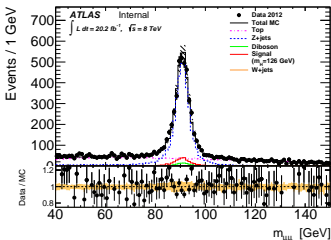
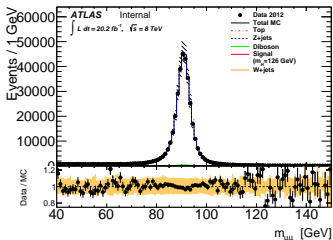
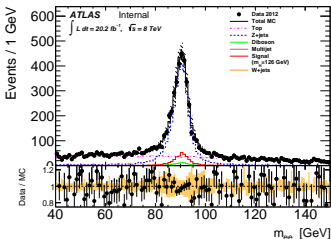
6 $A \rightarrow ZH \rightarrow llbb$ Results (Blinded)

- Good overall normalisation after “flavour fit” (see later)

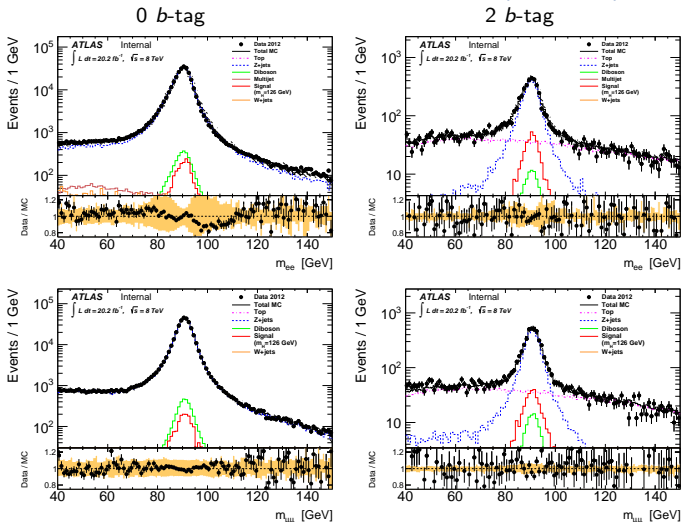
0 b -tag



2 b -tag

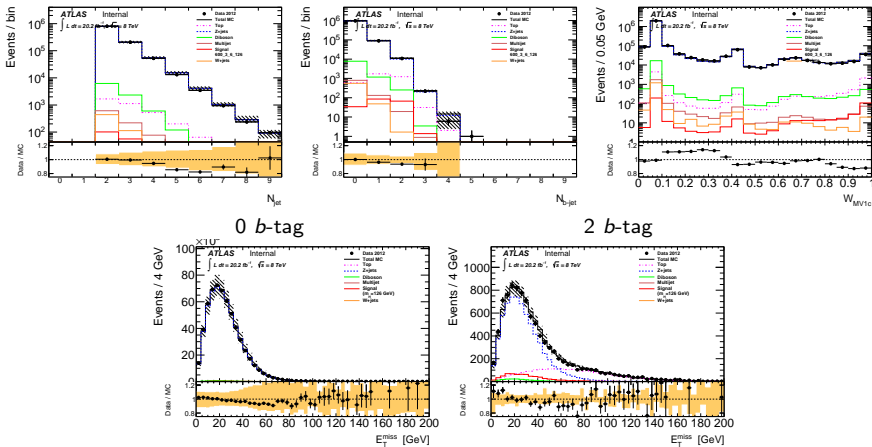


- Good overall normalisation after “flavour fit” (see later)

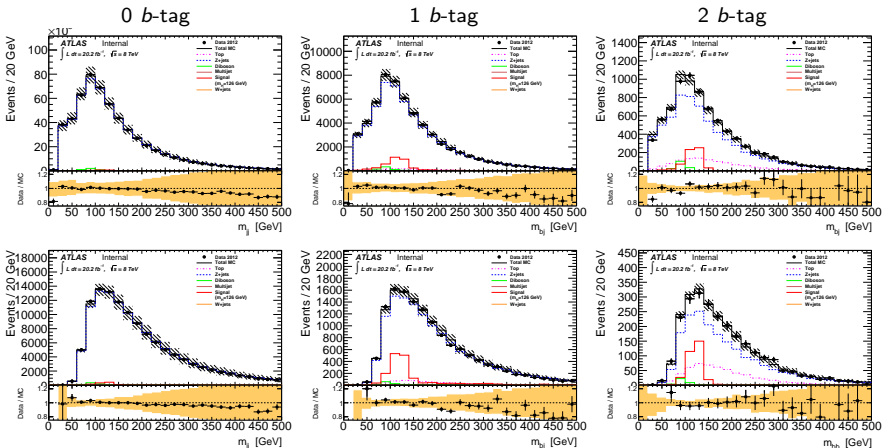


Jet + E_T^{miss}

- Slope in Data/MC for N_{jet} but 2 and 3 jet OK
- E_T^{miss} reasonably described but some slope

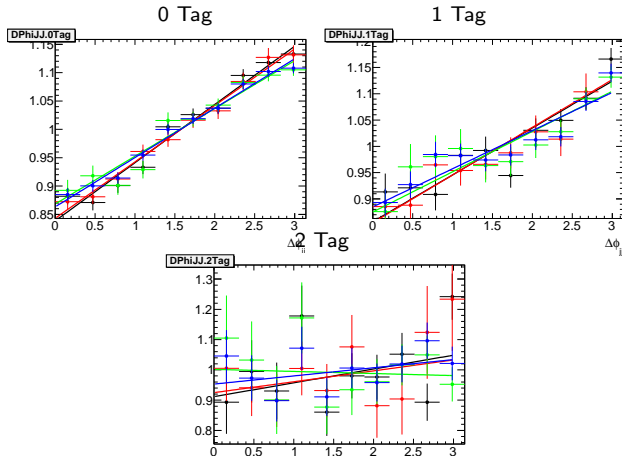


- Before (top) and after (bottom) optimised cuts
 - Some slope in ratio for 0/1 tag but SB only up to $m_{jj} = 180$ GeV



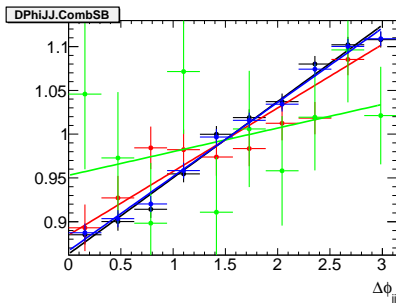
$\Delta\phi_{jj}$ Reweight

- Compare $\Delta\phi_{jj}$ ratio in SR, low SB, high SB and comb SB for 0/1/2 tag. Slopes are consistent. NB: these are $H \rightarrow ZZ \rightarrow llqq$ SBs



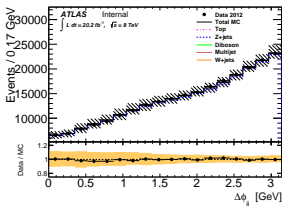
$\Delta\phi_{jj}$ Reweight (2)

- Compare $\Delta\phi_{jj}$ ratio in 0, 1, 2 and N tag for comb SB. Slopes are consistent except 2 tag, but very low stats.
- Fit for N tag is: $0.855 + 0.063\Delta\phi_{jj}$
 - Similar to HSG5 result: $0.88 + 0.0675$
 - Should double-check for MWT m_{jj} SBs

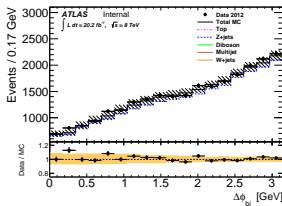


- Good description of $\Delta\phi_{jj}$ after reweight
 - Both in SB (top) and SR (bottom)

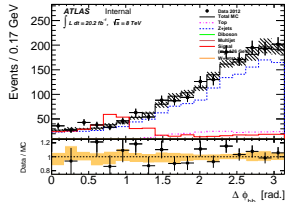
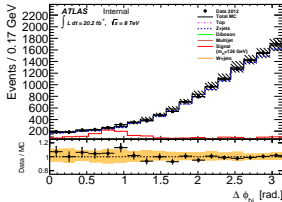
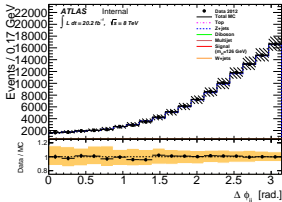
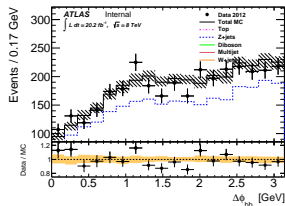
0 b-tag



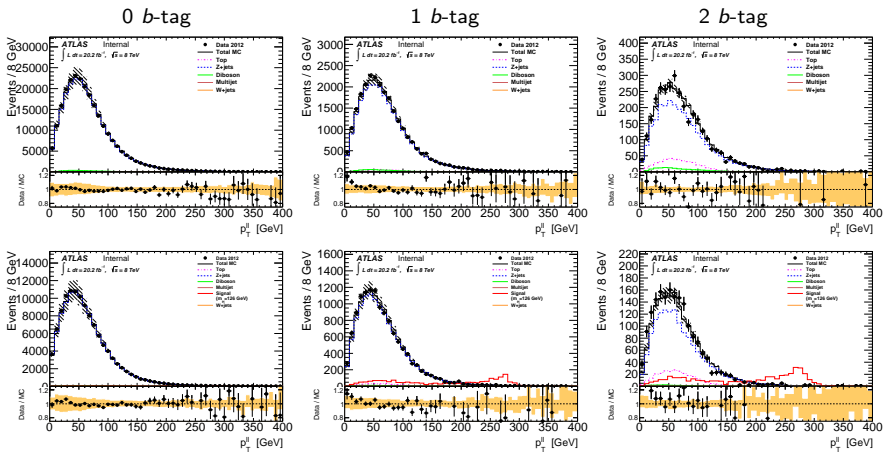
1 b-tag



2 b-tag



- P_T^Z in SB (top) and SR (bottom) also improved by $\Delta\phi_{jj}$ reweight





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Backgrounds (1)



- Reminder of HSG5 procedure ...
- Control regions
 - $V + l/c/b$ jets: 1 b -tag region
 - Top: 3 (4) jet events for 1 lepton
 $e\mu$ events (checked in m_{ll} SBs) for 2 lepton
- Simultaneous PL fit to m_{bb} in 3 channels and $P_T^V + \text{jet}/b\text{-tag}$ bins
 - $2/3 \text{ jet} \otimes 1/2 b\text{-tag}$ categories + 2-lepton top CRs
 - Constrains normalisation (inc 0 lepton) coherently + controls systematics
- Normalisation of main $V + \text{HF-jets}$ and $t\bar{t}$ background free to float
 - Smaller diboson, signal top and $V + \text{light-jets}$ fixed to MC
 - Multijet templates and normalisation extracted from data
- Very complicated final fit + doesn't constrain e.g. $V + c$ well
 - 1 b -tag has contribution from $V + l/c/b$ but m_{bb} has similar shape

Backgrounds (2)

- Now have first pseudo-continuous b -tagging, can fit b -tag discriminant
- Also, switch from MV1 to MV1C b -tagging discriminant
 - Similar light-jet rejection to MV1 but better c -rejection at looser operating points \rightarrow provides better constraint
- Using for $H \rightarrow ZZ \rightarrow llqq$ and HSG5 looking at MV1C too
- Perform “flavour fit” in m_{jj} SBs to:
 - a) First (highest $MV1C/p_T^{\text{jet}}$) jet MV1C weight for 0/1/2 tag
 - b) Sum of the MV1C weights for the two jets for 0/1/2 tag
 - Don't need to use SBs for 0/1 b -tag here but came from $H \rightarrow ZZ \rightarrow llqq$
 - M_{bb} for 2 b -tag M_{ll} SB (top)
 - Plan to switch to $e\mu$ CR (similar kinematics to SR)
- Float $Z + l$, $Z + c$, $Z + bl/bc$, $Z + bb$ and top SFs
- Can subsequently constrain overall Z +jets normalisation from m_{jj} SBs if needed

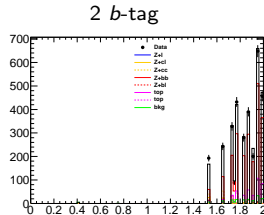
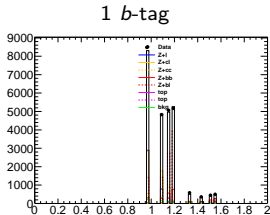
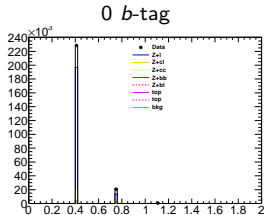
Flavour Fit Results

- Use sum of MV1C weights as default

- Take centre of each MV1c bin as weight → unique value for each combo (but not so easy to plot!)

Zb SF	1.19281e+00	2.89048e-02
Zbl SF	1.07645e+00	1.83006e-02
Zc SF	1.01938e+00	2.17676e-02
Zl SF	9.94183e-01	3.63502e-03
Top SF	1.01913e+00	1.42722e-02

— Zl
 — Zc
 Zbl
 — Zbb
 — Top
 — Other bkg

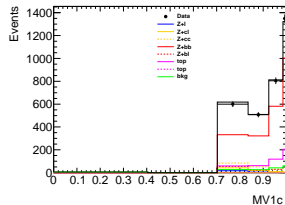
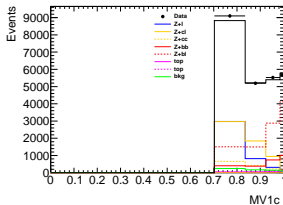
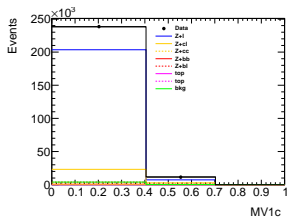


Flavour Fit Results (2)

- Results from first jet weight consistent with sum of weights

Zb SF	1.17096e+00	3.06898e-02
Zbl SF	1.08872e+00	1.91301e-02
Zc SF	1.02260e+00	2.27157e-02
Zl SF	9.93339e-01	3.75678e-03
Top SF	1.02112e+00	1.43003e-02

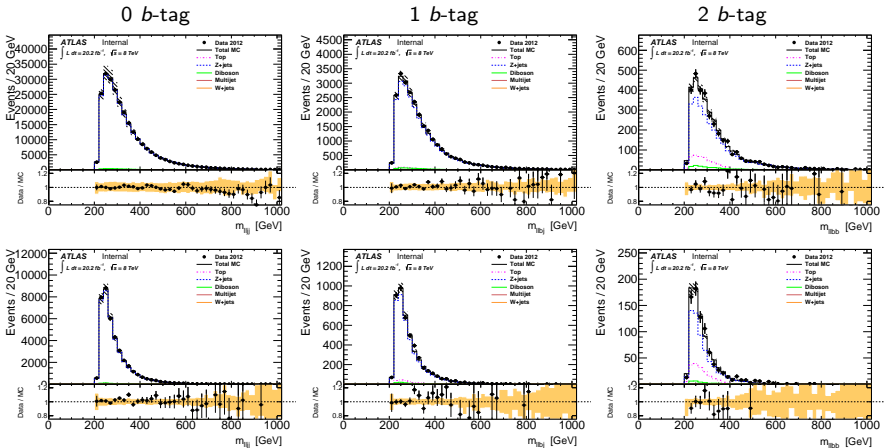
— Zl
 — Zc
 ... Zbl
 — Zbb
 — Top
 — Other bkg



Z+jets CR

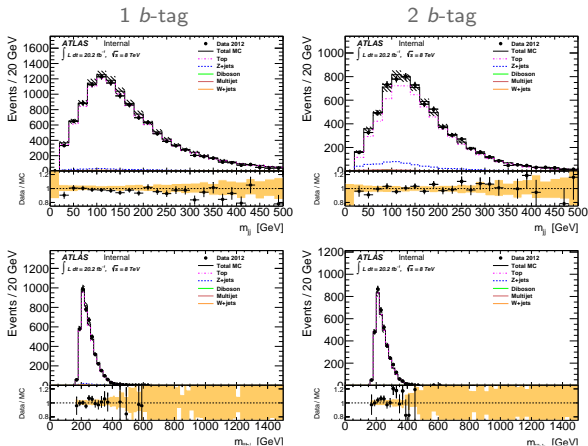
● m_{jj} SBs before (top) and after (bottom) optimised cuts

- $50 < m_{jj} < 105$ GeV or $145 < m_{jj} < 180$ GeV



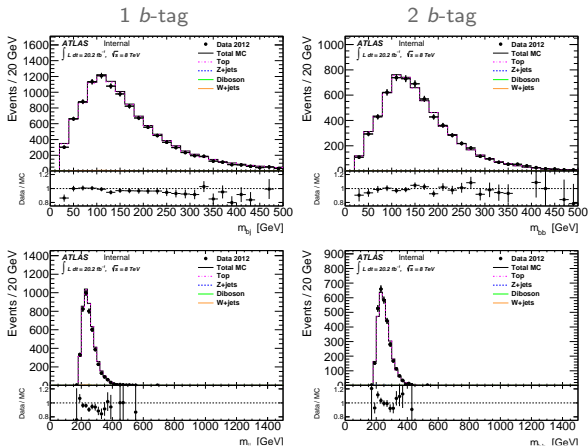
Top CR (SBs)

- m_{ll} SBs before (top) and after (bottom) optimised cuts
 - $40 < m_{ll} < 76$ GeV or $m_{jj} > 106$ GeV + $E_T^{\text{miss}} > 60$ GeV for 1 b -tag
- Good normalisation for 2 tag; a little low for 1 tag



Top CR ($e\mu$)

- $e\mu$ events with $m_{ll} > 40$ GeV \rightarrow increased stats/closer kinematics
 - Opposite sign only + $E_T^{\text{miss}} > 60$ GeV for 1 b -tag (remove QCD)
- Very consistent picture for Data/MC in $e\mu$ and SBs

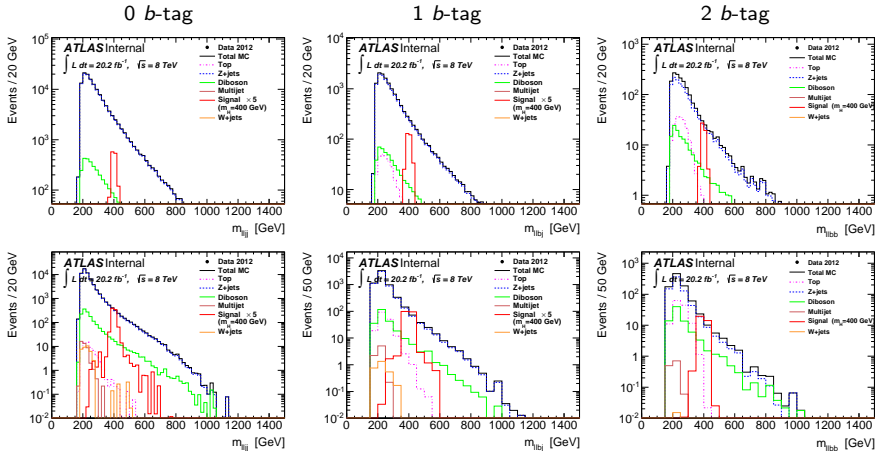




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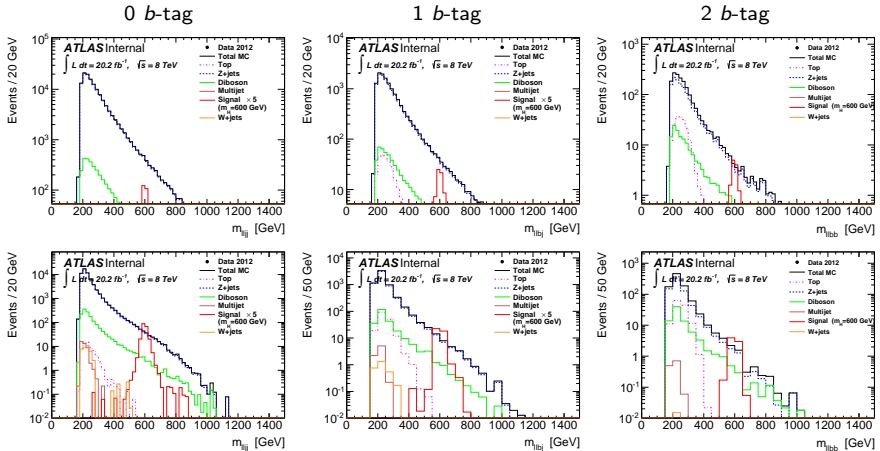
m_{lljj} @ 400 GeV

- Before (top) and after (bottom) optimised cuts



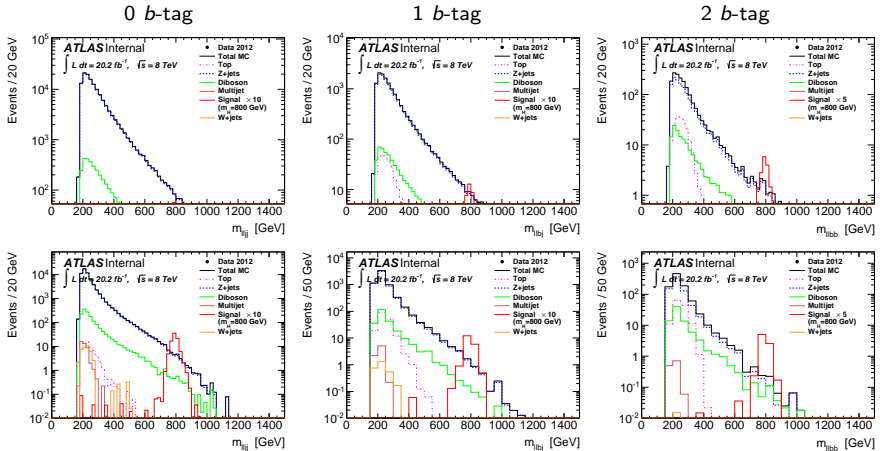
m_{lljj} @ 600 GeV

- Before (top) and after (bottom) optimised cuts



m_{lljj} @ 800 GeV

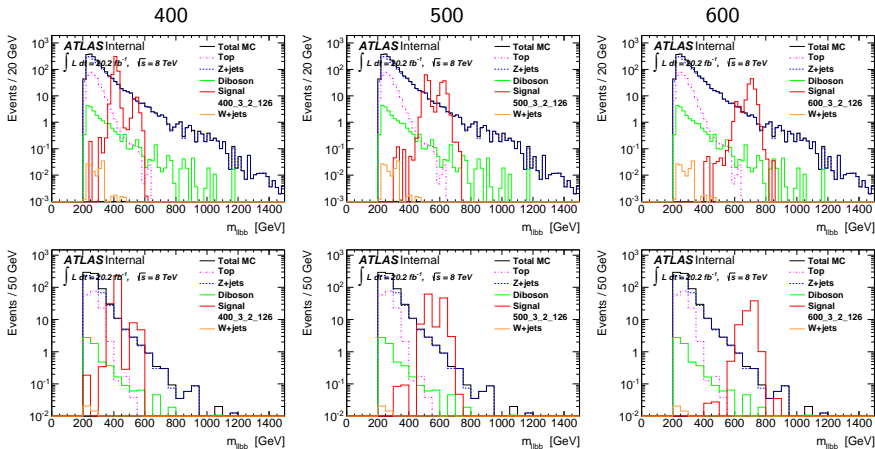
- Before (top) and after (bottom) optimised cuts



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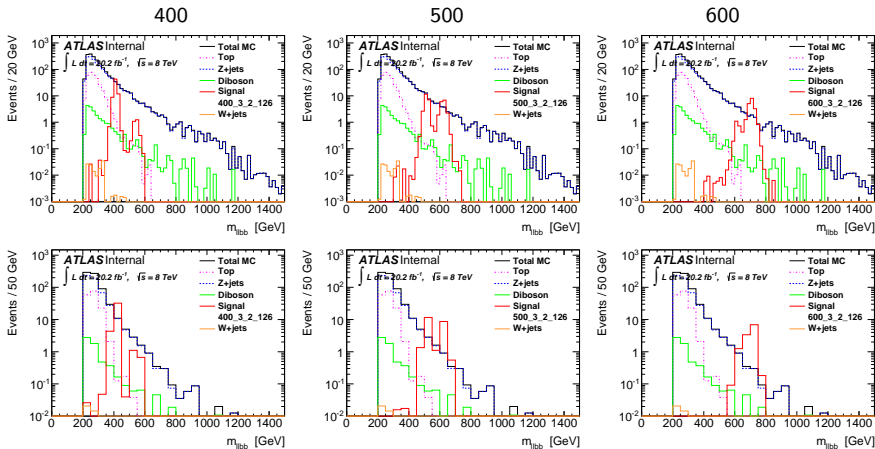
m_{lljj} ($\tan \beta = 1$)

- Double-peak at some m as MWT has 2 closeby resonances (R_1/R_2)
- Optimised cuts improve sensitivity



m_{lljj} ($\tan \beta = 10$)

- Double-peak at some m as MWT has 2 closeby resonances (R_1/R_2)
- Optimised cuts improve sensitivity



Summary



- Close to full analysis profiting from HSG5/HSG2 and MWT work
 - Background modelling/normalisation
 - Most systematics
 - Jike has limit setting machinery in place