Boosted Higgs in ATLAS

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On behalf of ATLAS collaboration

9th Nov 2017

Higgs Coupling Heidelberg

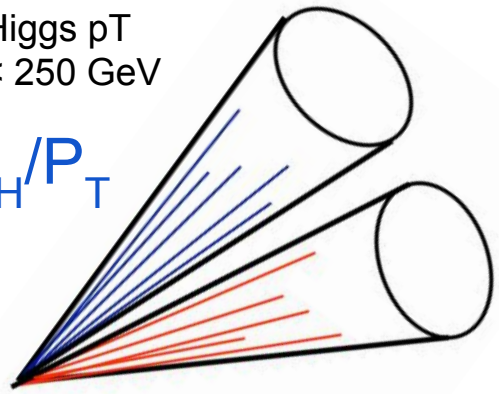
Introduction

- Focus on boosted Higgs->bb
- LHC 13 TeV with increased integrated luminosity
  - boosted Higgs->bb topology
    - H->bb 57% branching fraction
    - Collimated bbbar pair
    - Identify (tag) boosted Higgs-jets
- Analysis that may benefit
  - Di-boson resonance
    - X->VH-> vvbb, lvbb, 2l2b (36.1/fb)
    - X->VH-> qqbb (36.1/fb)
    - X->HH-> 4b (13.3/fb), 2b2γ(3.2/fb), 2b2τ (20.3/fb, 8 TeV)
  - Heavy resonance (associated new particle production)
    - Y->XH->qqbb (36.1/fb)
  - Dark Matter
    - Mono-Higgs->bb (36.1 /fb, in Ben's talk)
  - Standard model Higgs
    - VH->bb (36.1 /fb)

Resolved region

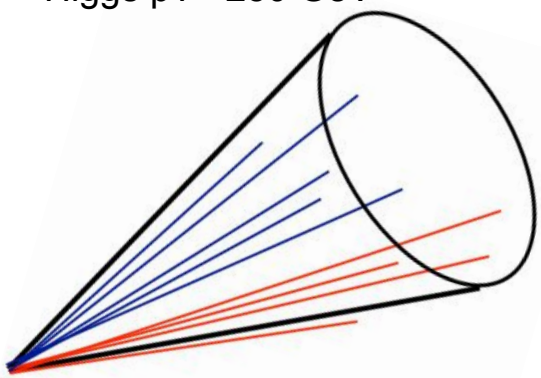
2 b jets
R=0.4
Higgs pT
< 250 GeV

$dR(bb) \sim 2m_H/P_T$



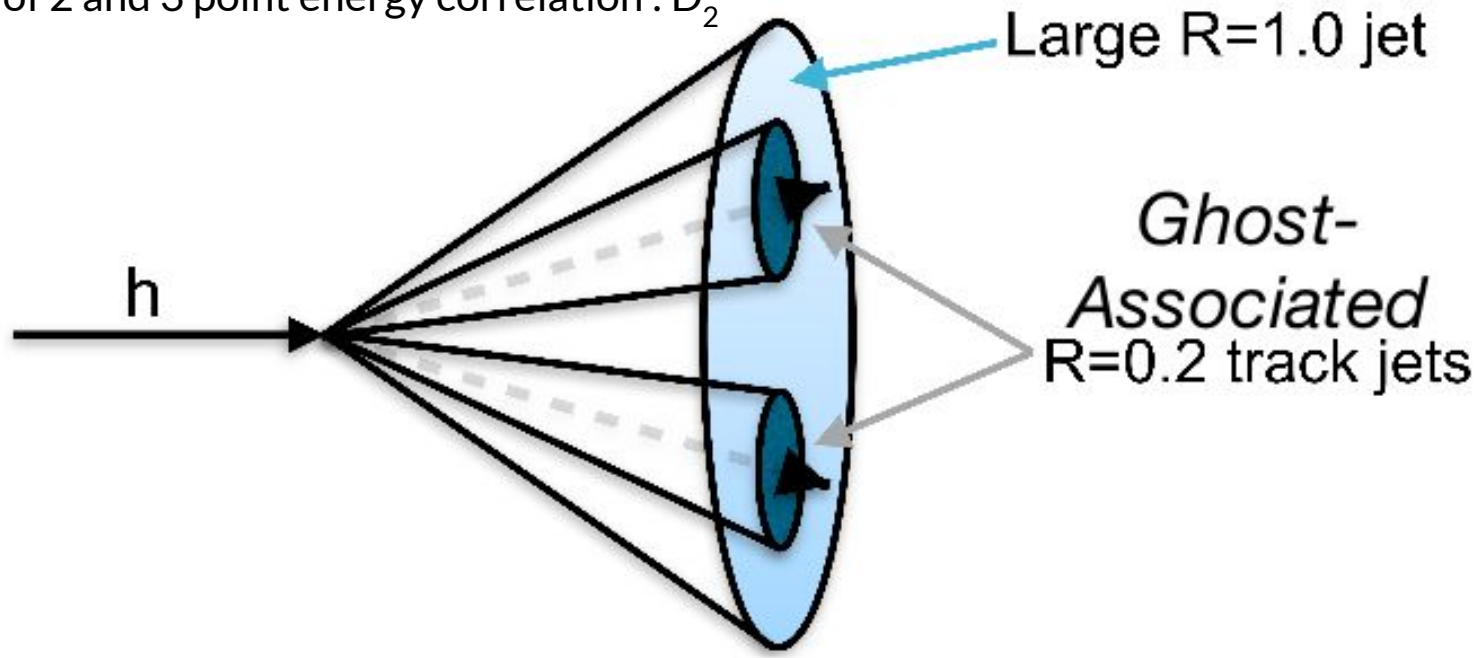
Merged region

Higgs-jet
R=1.0
Higgs pT >250 GeV



Identification of Higgs jets

- B hadron identification
  - Single anti-KT large R 1.0 trimmed calo jet
  - 0.2 track jet ghost associated to large R jet (subjet)
  - Subjet btag : jet p_T dependent cone size for track to jet association
- Higgs mass window
  - Combined mass
- Jet substructure
  - Ratio of 2 and 3 point energy correlation : D_2



Large-R jet mass

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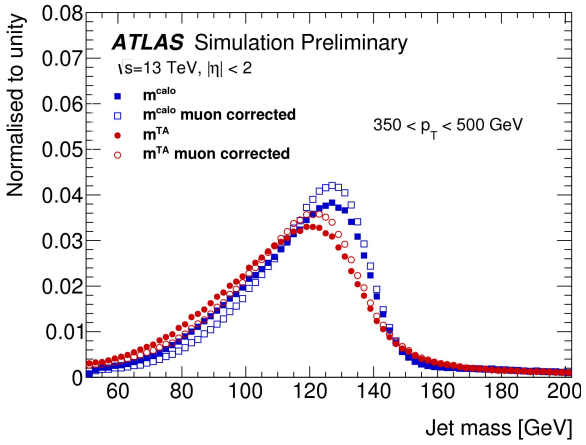
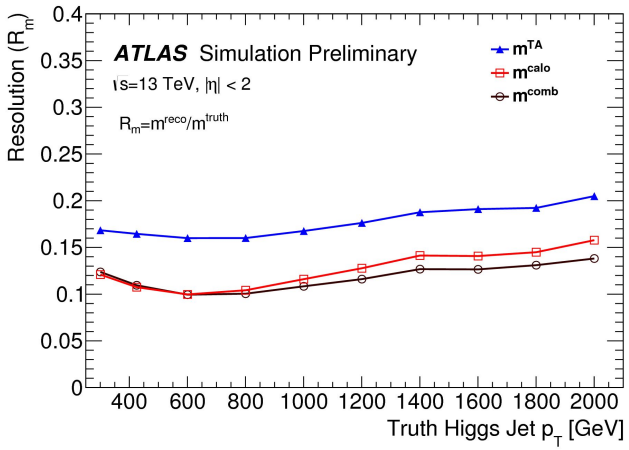
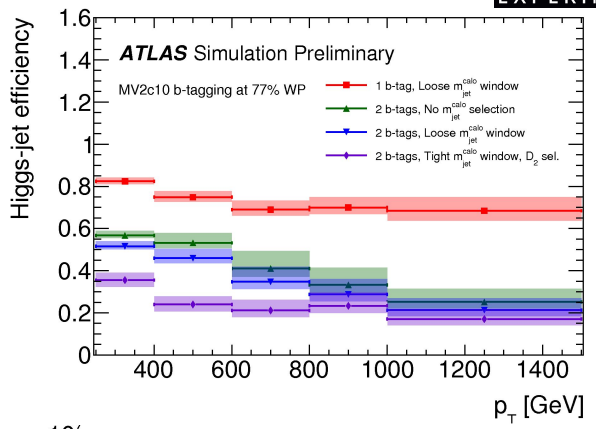
- m_{combine} (combined mass)

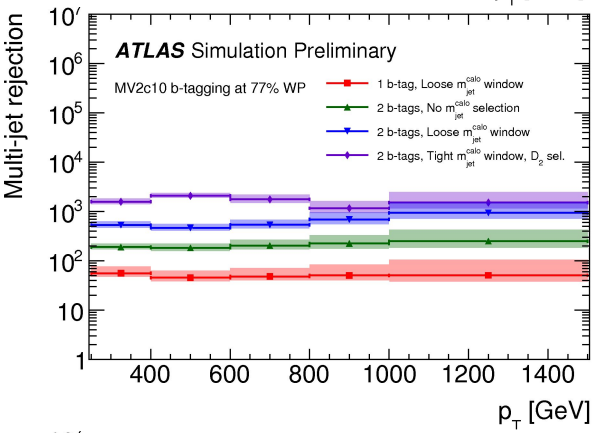
$$m_J \equiv w_{\text{calo}} \times m_J^{\text{calo}} + w_{\text{track}} \times \left(m_J^{\text{track}} \frac{p_{\text{T}}^{\text{calo}}}{p_{\text{T}}^{\text{track}}} \right)$$

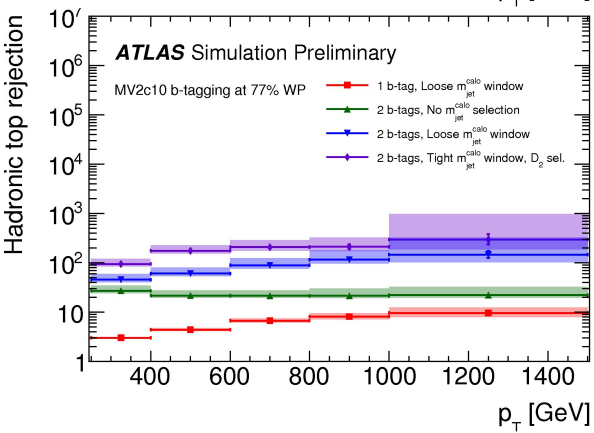
- Improved Higgs jet p_T > 1000GeV
- Muon correction
- Large-R jet mass window
  - 93-134 GeV (68% Higgs-jet efficiency)
  - 76-146 GeV (90% Higgs-jet efficiency)











Track jet b tagging

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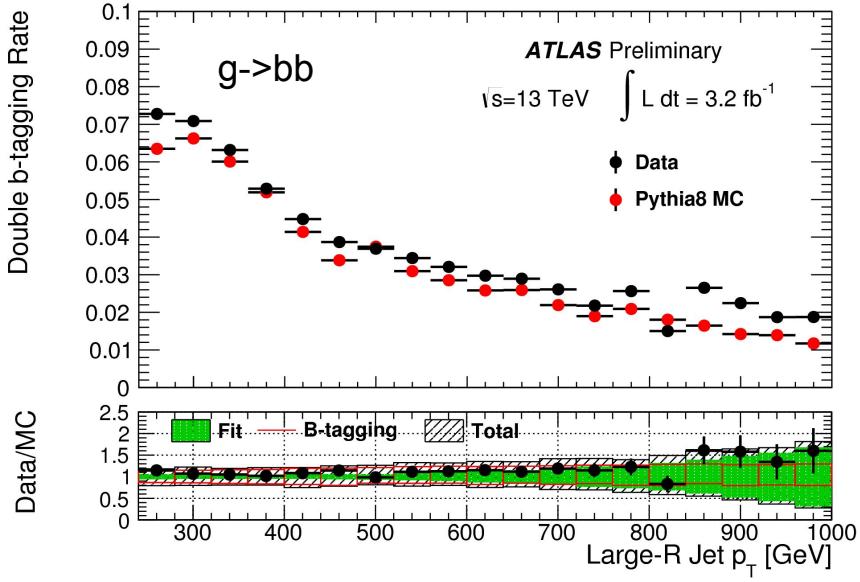
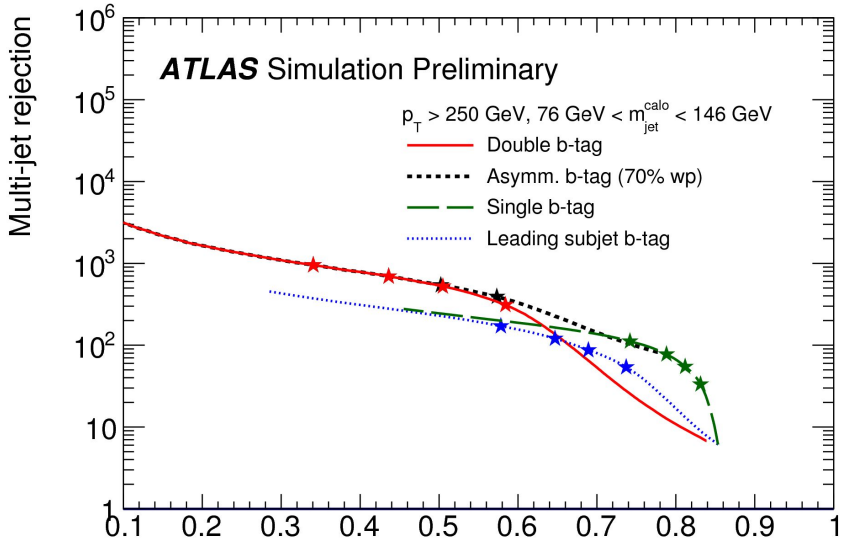
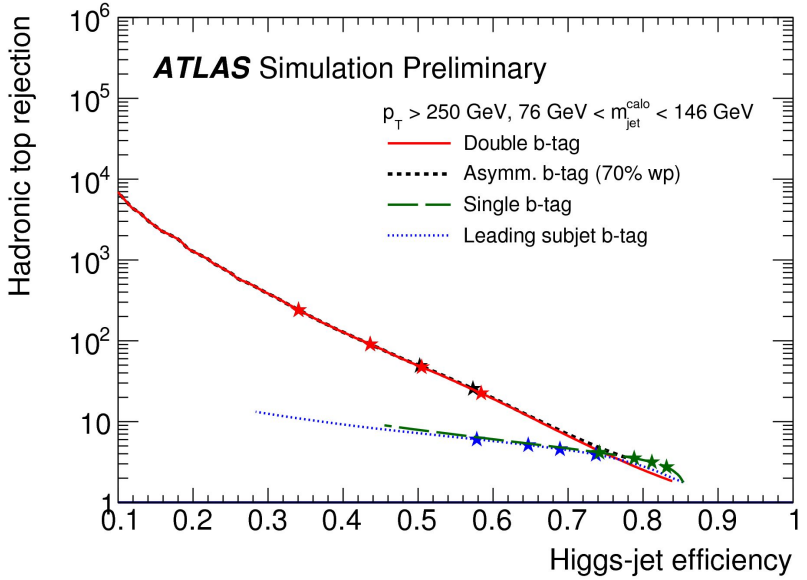
Double btag : 2 leading pT trackjet
Single btag : At least one of the 2 leading trackjet
Asymm btag: Largest btag weight passed 70% WP,
The other pass varied WPs
Leading Subjet btag : Leading pT track Jet pass WPs

- High efficiency region
  - Single btag has better performance
- Low efficiency region
  - Double b tag and Asymm btag have similar performance





Mv2c10 60%,70%,77%,85% btag WPs



Application of Hbb tagging in Analysis

Search for high-mass diboson resonances

X->VH->vvbb, lvbb, 2l2b

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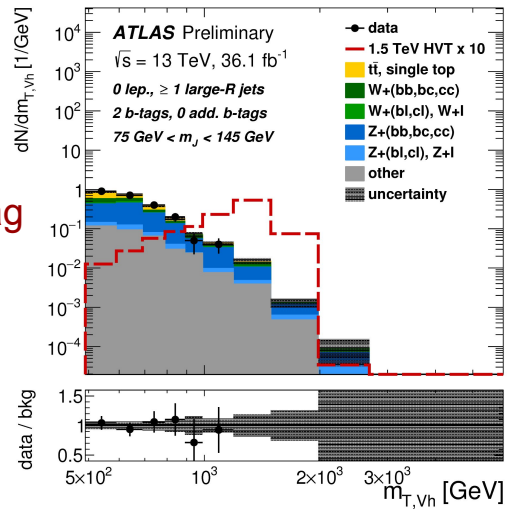
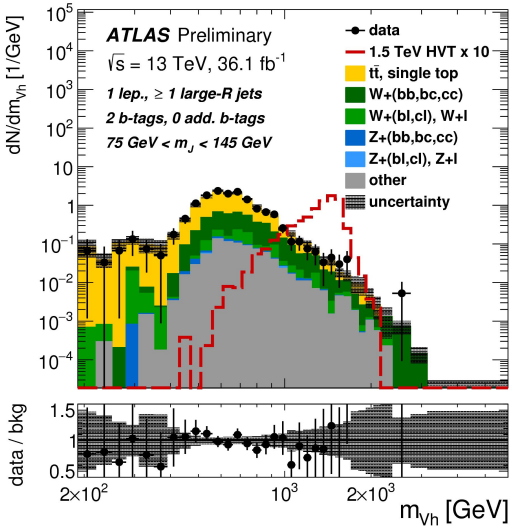
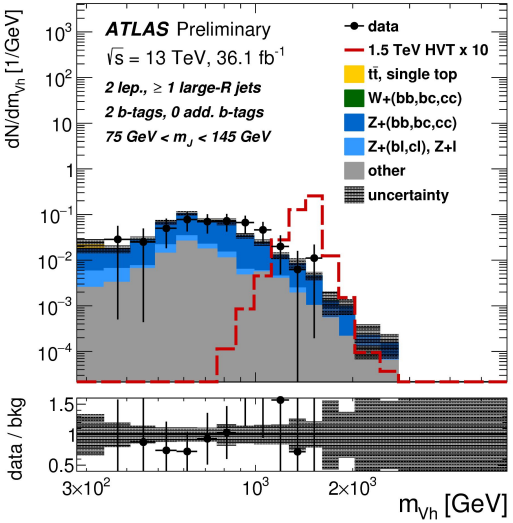
- 0,1 lepton. 1,2 btag region (W') ; 0,2 lepton. 1,2 btag(Z' and A boson)
- At least one large-R jet with at least 1 ghost associated 0.2 track jet, leading jet p_T > 250 GeV; ~ 90% Higgs-jet efficiency mass window cut
- Different background fraction in each signal region
  - Background estimation with shapes from simulation, normalization from data except mutijet background in 1 lepton channel
  - Mutijet background template in 1 lepton channel is extract from non-isolated leptons
  - Hadron cone base truth labeling template for W/Z + bb,bc,cc,bl,cl,ll

0 lep | 1 lep | 2 lep

2 btag

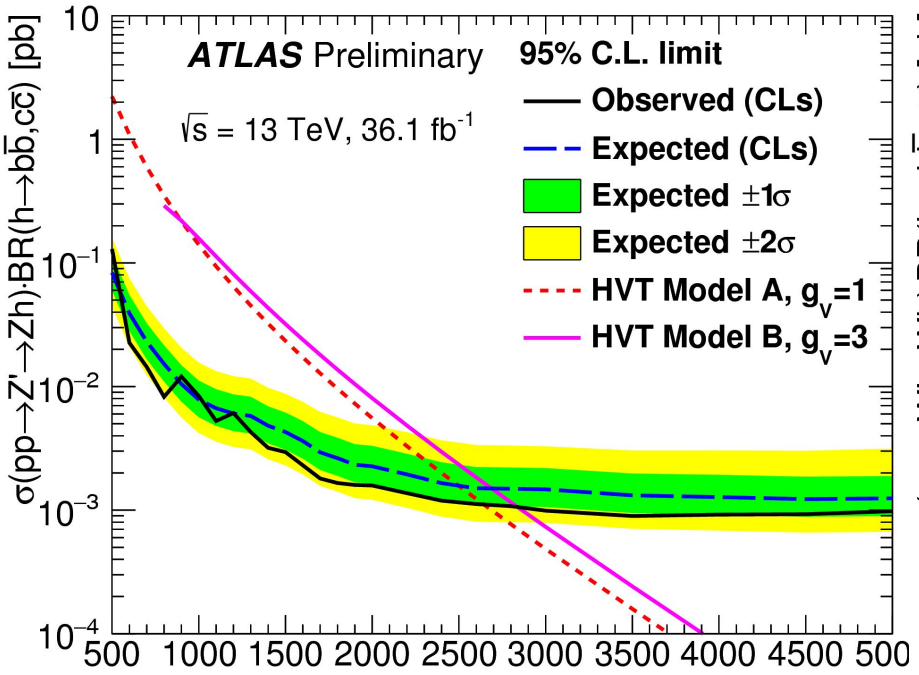




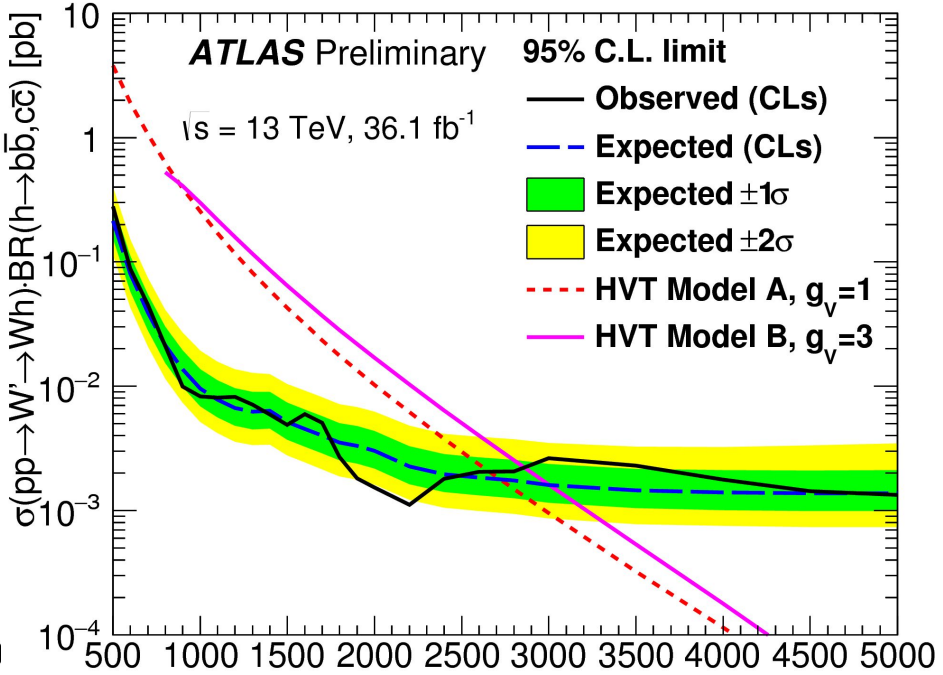


Heavy Vector Triplet (HVT)

- W'->W+-h and Z'->Zh
  - Model A: comparable BRs to fermions and gauge bosons
  - Model B: suppressed couplings to fermions



Model A excluded : < 2.65 TeV
Model B excluded : < 2.83 TeV

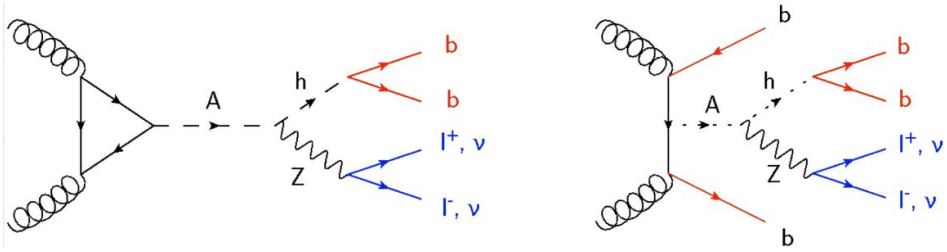


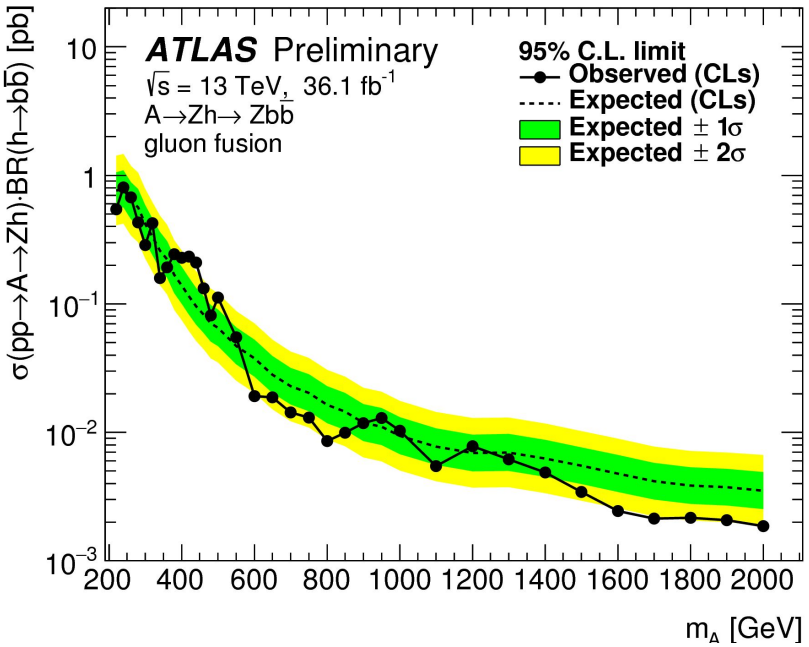
Model A excluded : < 2.67 TeV
Model B excluded : < 2.86 TeV

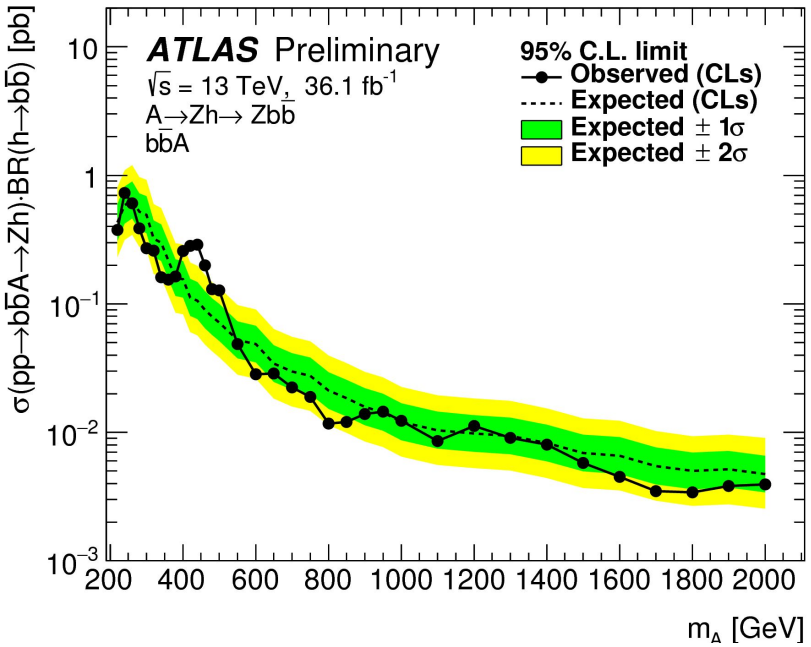
A->ZH->vvbb, 2l2b

ATLAS-CONF-2017-055/

- A->ZH : CP odd scalar boson A in Two Higgs-Doublet models
- Two Higgs-Doublet models
  - mA=mH=mH^{+-}, mh=125 GeV
- Merged signal region
  - 1,2 b-tag and (additional btag 0.4 track jet) combined 1, 2 btag for the 2 lepton channel
- Mild excess at m_A = 440 GeV: Local (global) significance: 3.6σ (2.4σ)

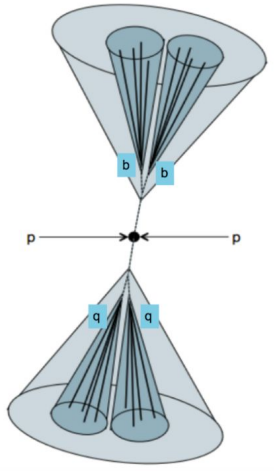




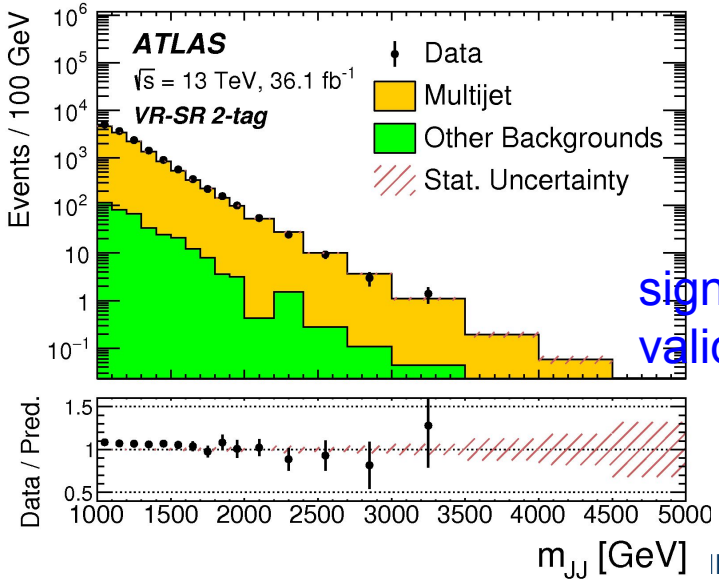


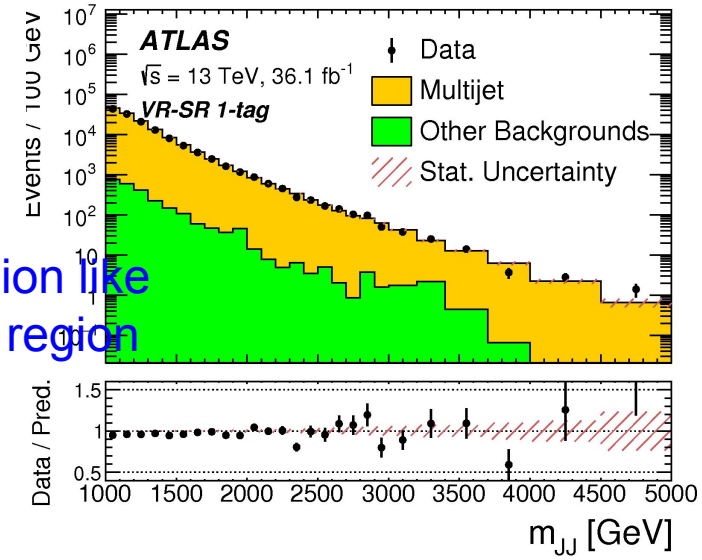
X->VH->qq(')bb

EXOT-2016-12/



- Search for heavy resonances decaying to VH in all hadronic channel
  - M_{VH} > 1 TeV ; V and H are highly boosted
  - Veto lepton to ensure the orthogonality to non-fully hadronic state
- 2 large R jet p_T > 450 GeV, 250 GeV (larger M_J: H, smaller M_J: V)
  - At least 1 ghost associated 0.2 track jet
  - 90% Higgs-jet efficiency mass window cut
  - One or two btag(77%) trackjet
- Main Background from Mutijet(~ 90%)
  - Use 0-tag sample(99% mutijet) to model kinematics of Mutijet in 1 and 2 tag
  - High mass sideband of H-jet for normalizing 0 tag sample to 1 and 2 tag sample

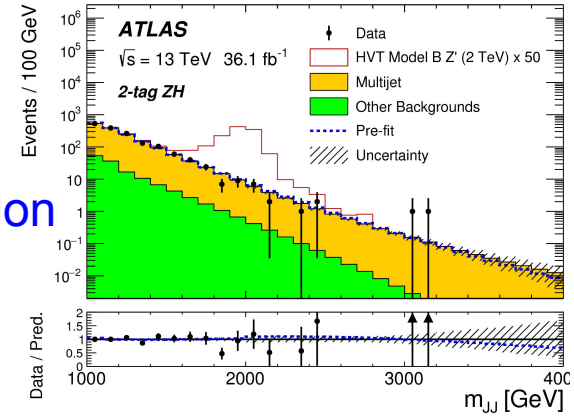


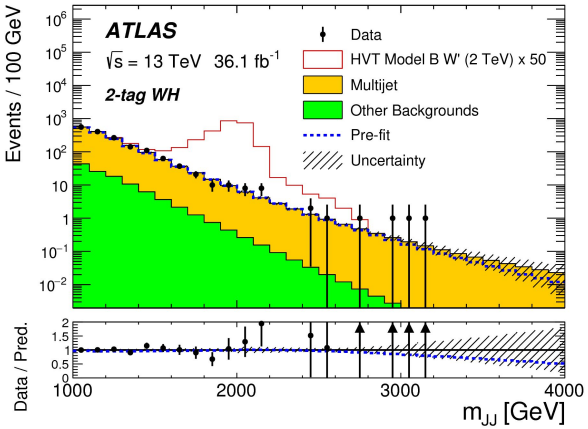


signal-region like validation region

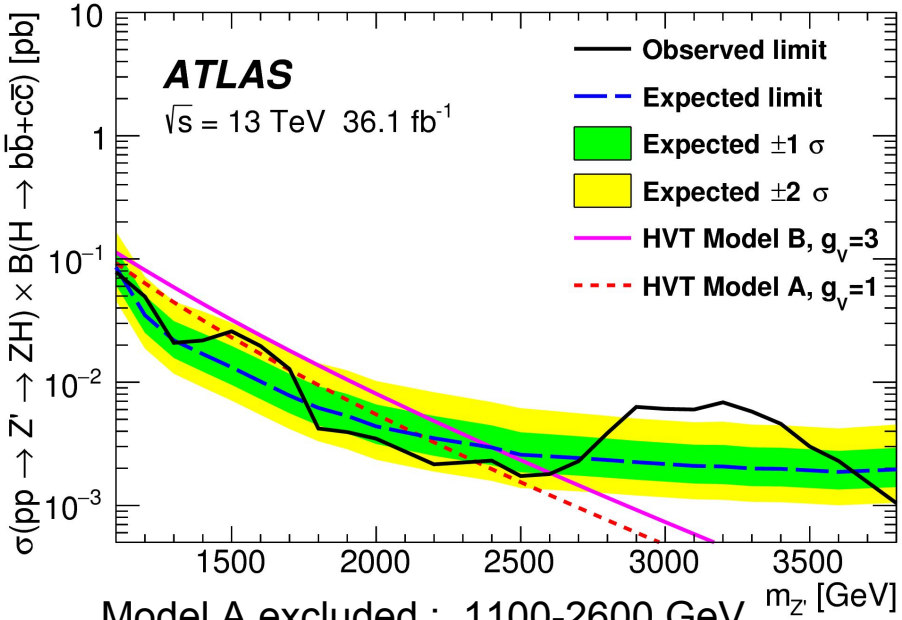
X->VH->qq(‘)bb

M_{JJ} spectrum for 2 tag signal region



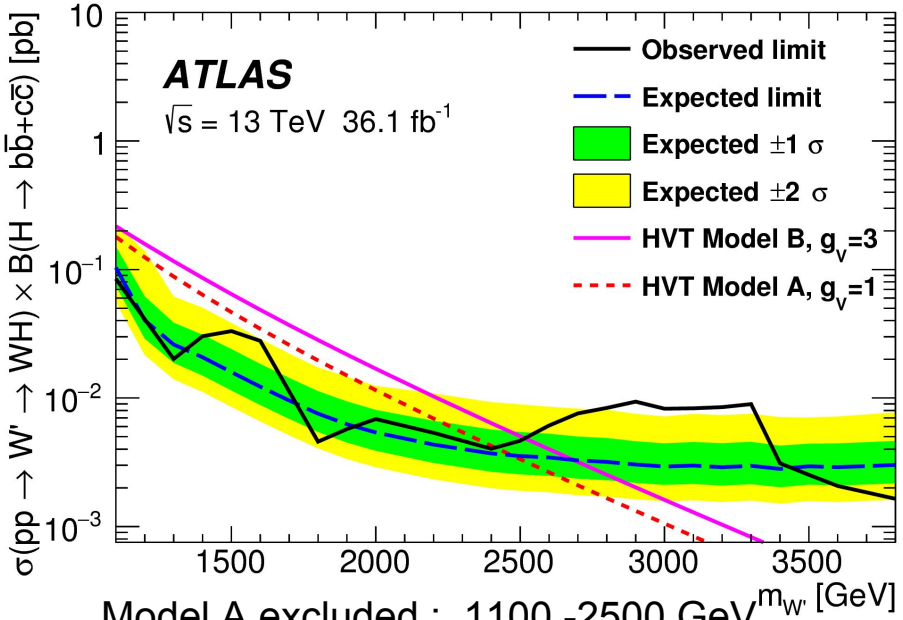


➤ Heavy Vector Triplet (HVT) W’->W+-h and Z’->Zh



Model A excluded : 1100-2600 GeV

Model B excluded : 1100-1480,1700-2350 GeV



Model A excluded : 1100 -2500 GeV

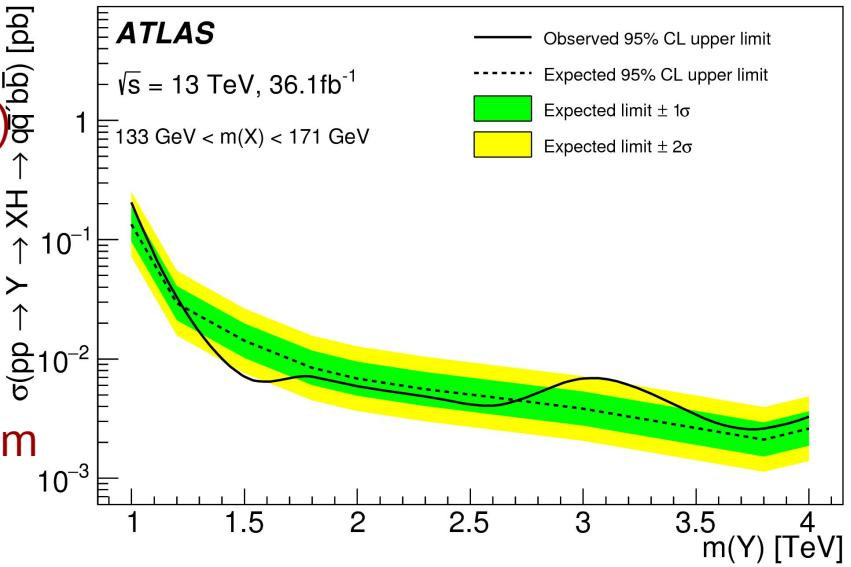
Model B excluded : 1100 -2400 GeV

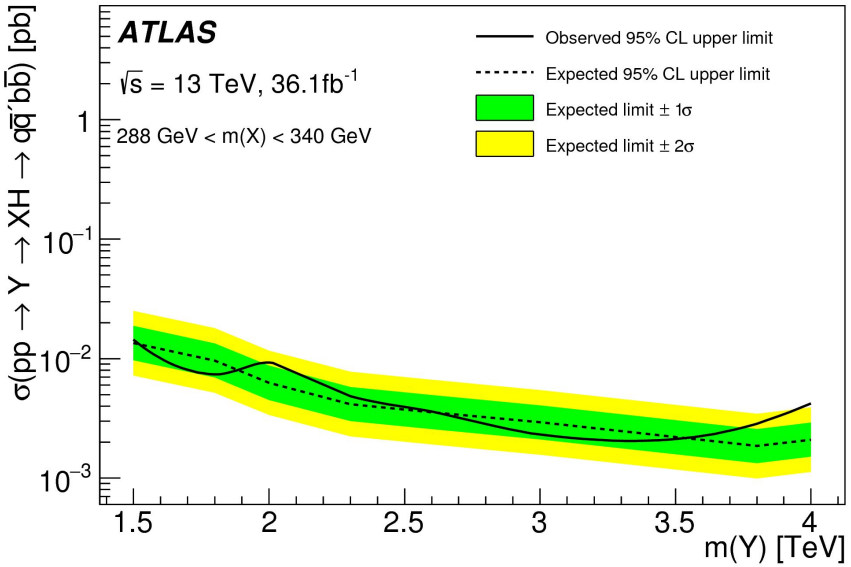
Y-> XH -> qqbb

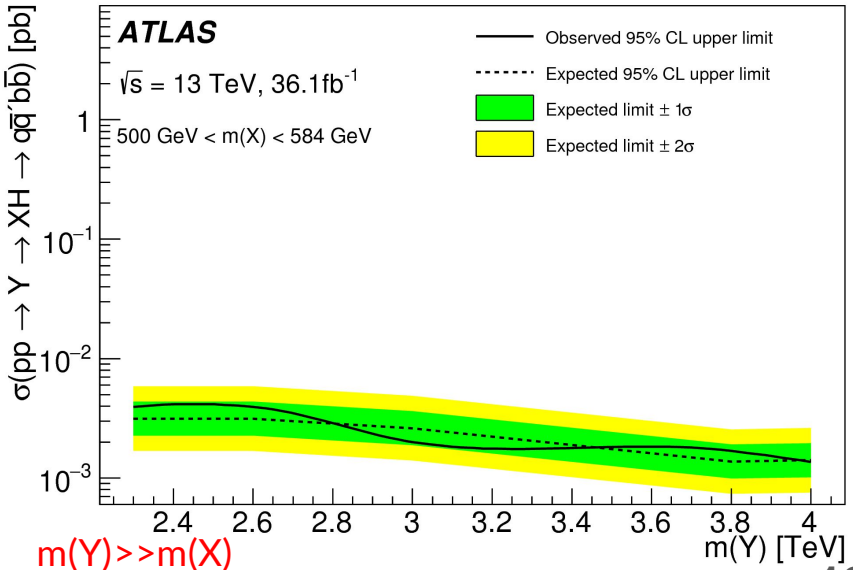
EXOT-2017-04/

- Assume X decays hadronically into light quark pair
- At least 2 large R jets (p_T>250, M_J>50 GeV)
  - Leading jet p_T 450 GeV; (H, X) : 2 leading jets; Select Higgs jet (M_J Win, n btag, p_T)
  - 90% Higgs-jet efficiency mass window
  - 1,2 btag(77%) signal region
- Evidence of an excess in XH mass spectrum
  - 2.5σ (1.2σ) local(global) significance

Main background from Mutijet(~ 96%)
Mutijet estimated with Higgs jet mass sideband





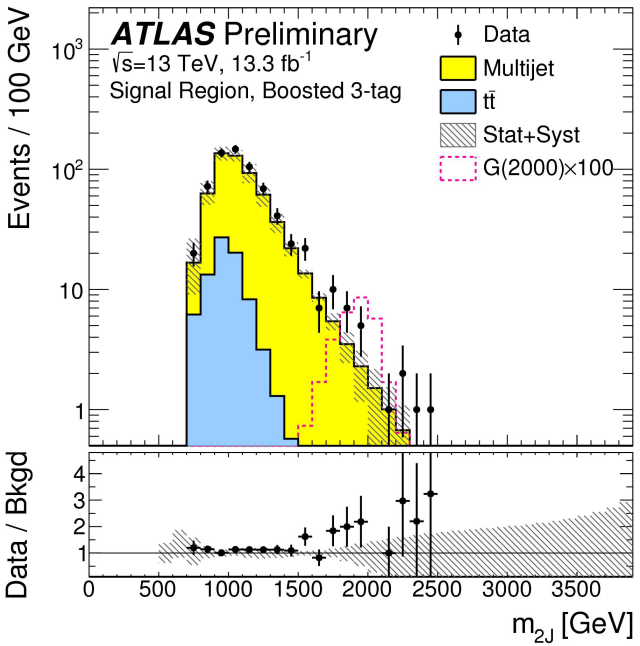


m(Y)>>m(X)
modified HVT m(Y):1-4TeV, m(X): 50-1000 GeV

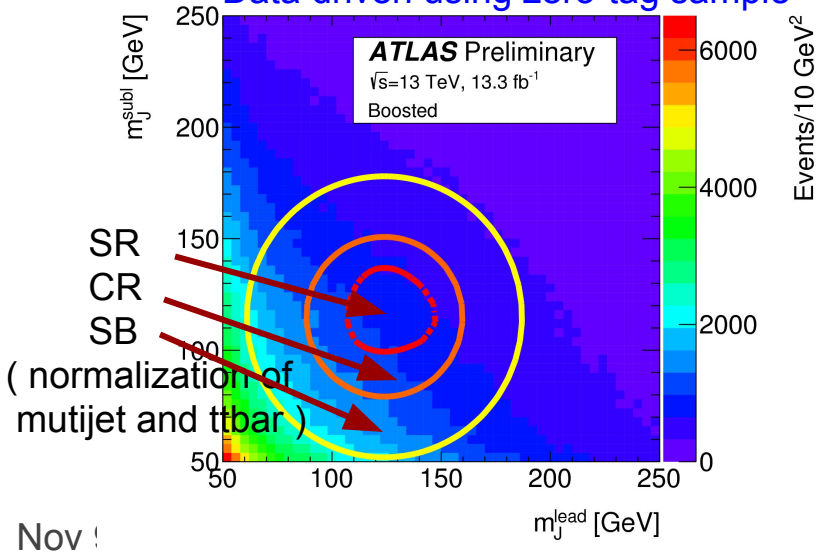
X->HH->4b

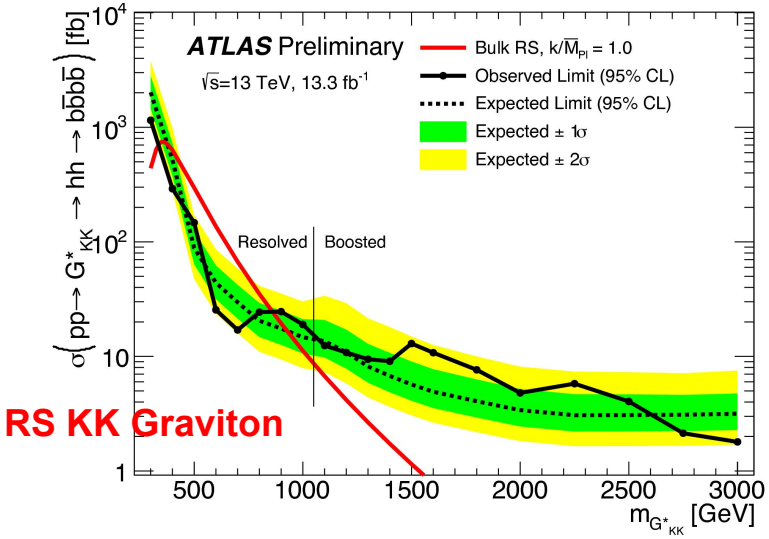
ATLAS-CONF-2016-049/ 13.3/fb

- At least 2 large-R jets with p_T > 250 GeV
  - Leading jet pT > 450 GeV
  - At least 1 0.2 track jets ghost associated
  - Each large-R jet 1 btag, 3 btag, 4 btag (77%)
  - m_J > 50 GeV, 2-d Higgs-jet mass window
- Not yet sensitive to SM prediction
- Resonant Higgs-boson pair production
  - Boosted analyses better sensitivity mass > 1000 GeV



Main Background from Mutijet (83%-87%)
Data driven using zero-tag sample

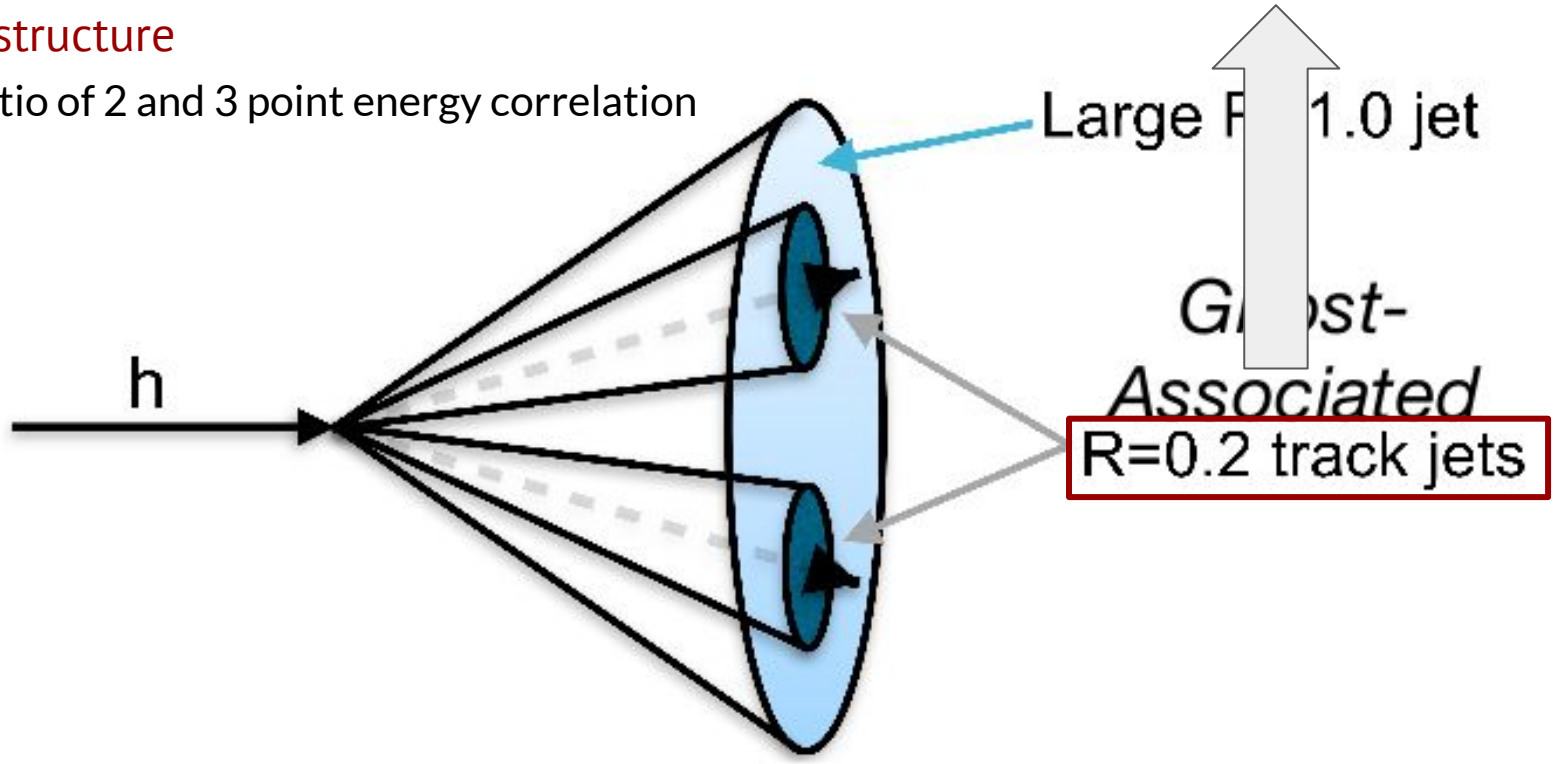




Identification of Higgs jets

- B hadron identification
  - Single large R 1.0 jet
  - 0.2 track jet (subjet)
  - Subjet btag
- Higgs Mass window
  - Combined mass
- Jet substructure
  - Ratio of 2 and 3 point energy correlation

Improvements for subjet reconstruction !!



Variable-R Track Jets

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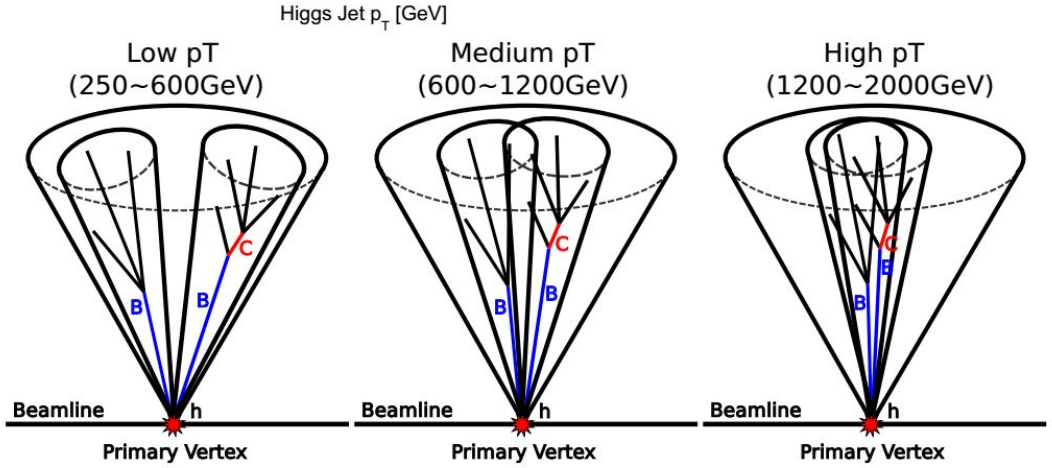
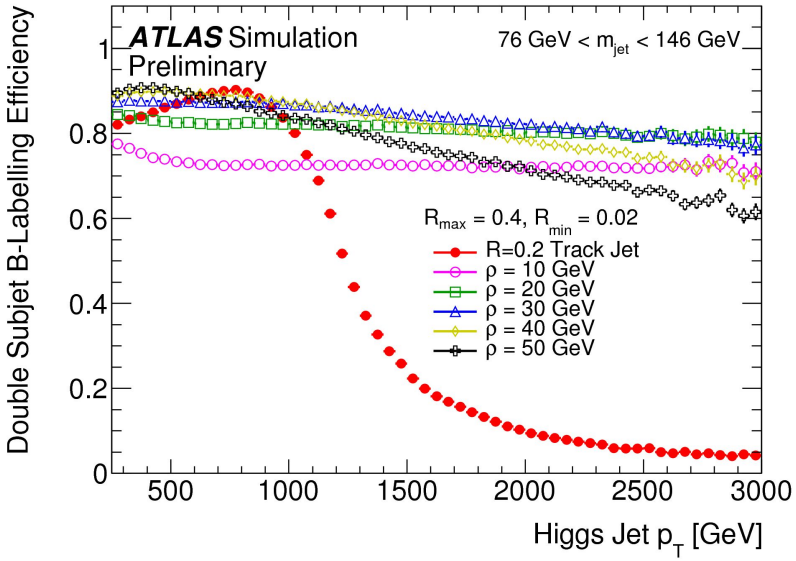
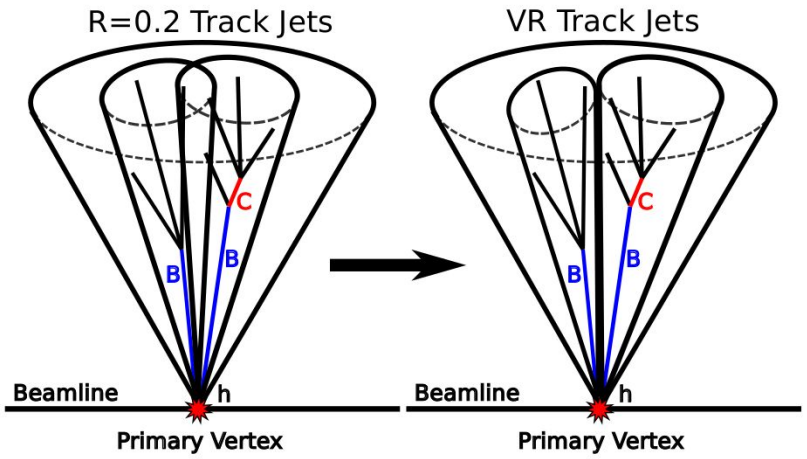
- Radius as a function of jet P_T

$$R \longrightarrow R_{\text{eff}}(p_{\text{T}}) = \frac{\rho}{p_{\text{T}}}$$

- Optimized parameters based on truth subjet double b-labeling
  - ρ = 30 GeV
  - Rmax = 0.4
  - Rmin = 0.02







Exclusive-k_T Subjets

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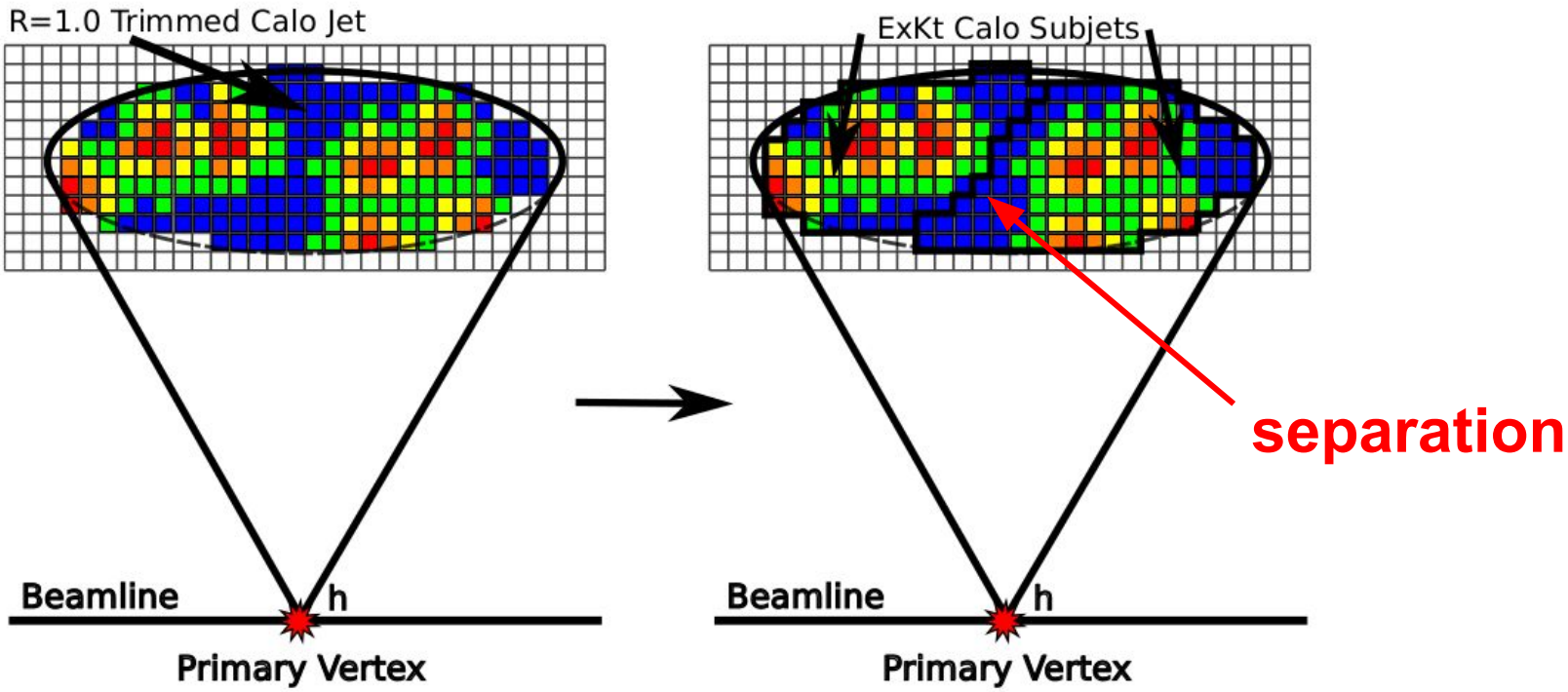
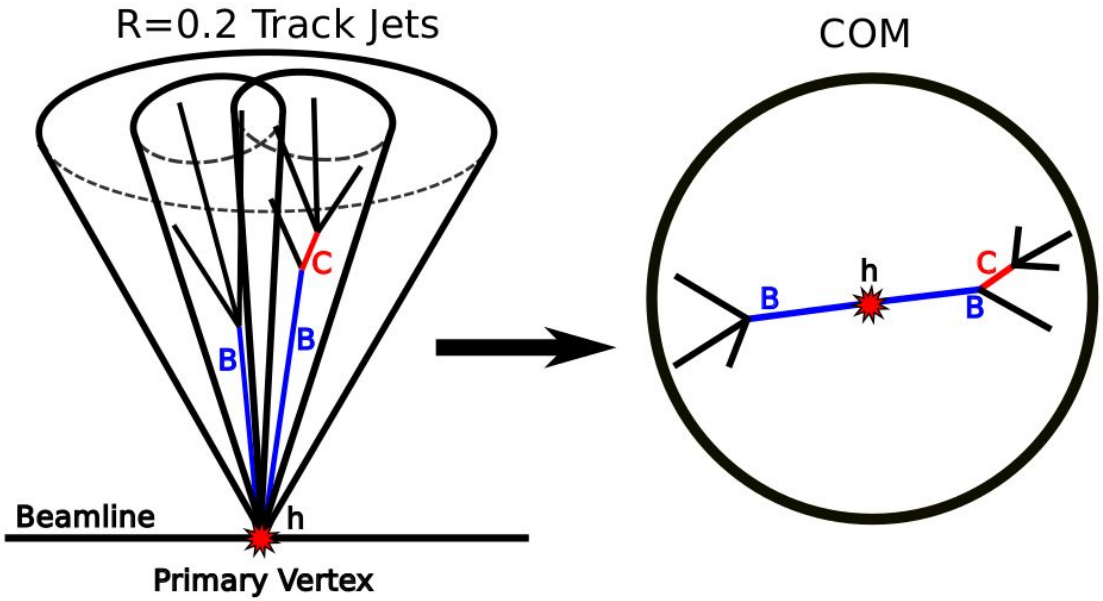
- Recluster large R jet constituents with Exclusive-k_T algorithm
  - Select different inputs based on best truth subjet double b-labeling efficiency
  - Trimmed large R calo jet constituents
- Large -R jet is divided into two components



Center of Mass

ATL-PHYS-PUB-2017-010/

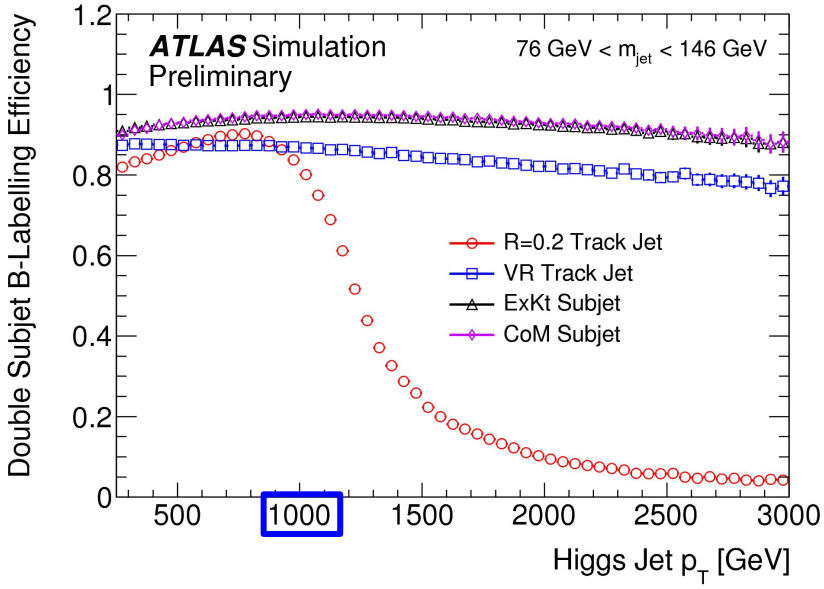
- Boost to center of mass large R calo jet
  - Subjets are reconstructed with calorimeter cell clusters (constituents of Large R jet)
  - Fixed cone size in CoM frame
- Track to jet association
  - Associated tracks to large R jet with 1.0 cone in lab frame
  - Boost to CoM to associate track to 2 subjets with fix cone
- Adapted variable cone size in lab frame
  - Cone size depends on jet momentum and Higgs decay topology

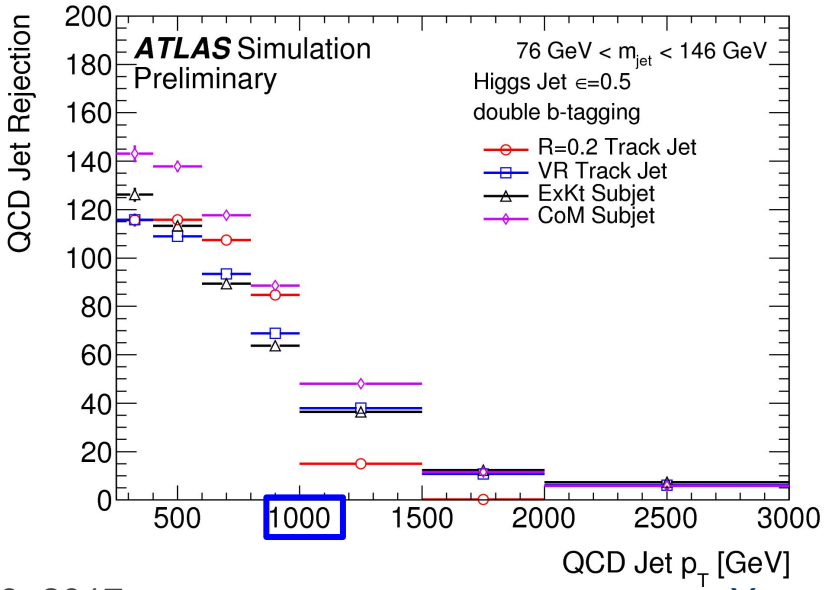


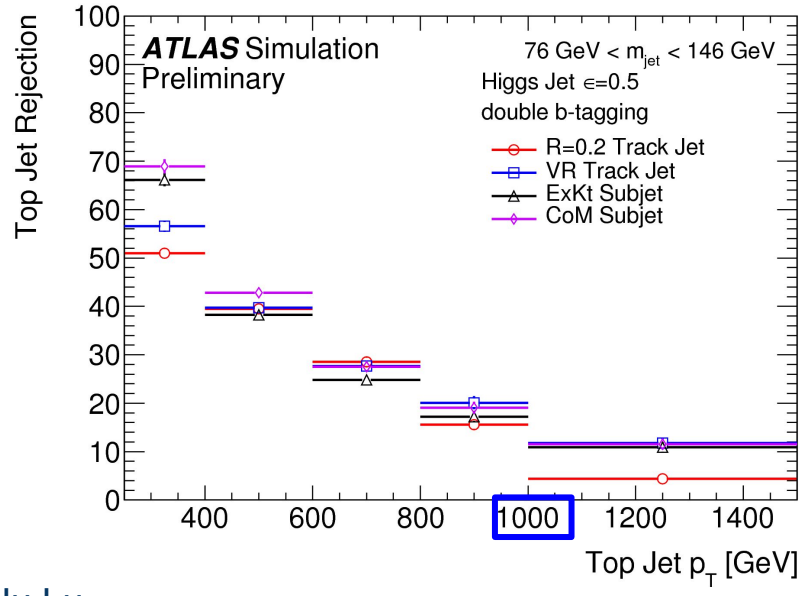
Performance

ATL-PHYS-PUB-2017-010/

- Testing 3 new subjet reconstruction methods
- Improved truth subjet double b-labeling efficiency
- Better QCD and Top jet rejection
- Big improvement for Higgs jet > 1000 GeV







Summary of boosted Higgs (bb) in ATLAS

- Di-boson resonance
  - X->V(vv,lv,ll)H(bb) (included boosted!)
  - X->V(qq)H(bb) (boosted region!)
  - X->HH-> 4b (included boosted!)
  - X->HH-> 2b2τ
  - X->HH-> 2b2γ
- Heavy resonance decay to Higgs with associated new particle production
  - Y->XH->qqbb (boosted region!)
- Dark Matter
  - Mono-Higgs->bb (included boosted!)
- Standard model Higgs
  - VH->bb
    - No boost Higgs included yet. Evidence !
- Exciting moment for boost Higgs analyses
  - Many analyses have sensitivity in boosted Higgs region and applied baseline techniques in ATLAS
  - New subjet reconstruction methods have shown significant improvements
  - Studies of the application of CoM, VR, ExKt in analyses are underway

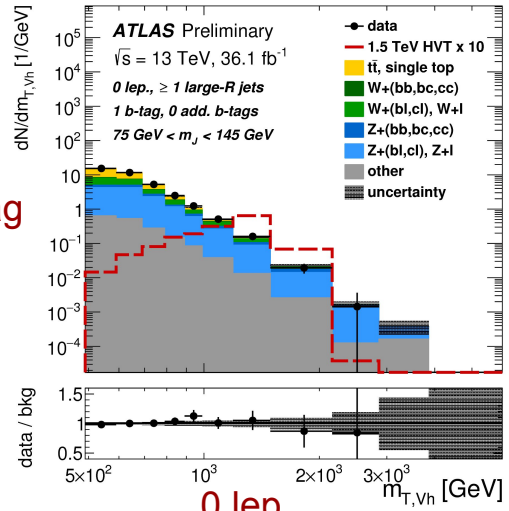
Thank you !

Back up

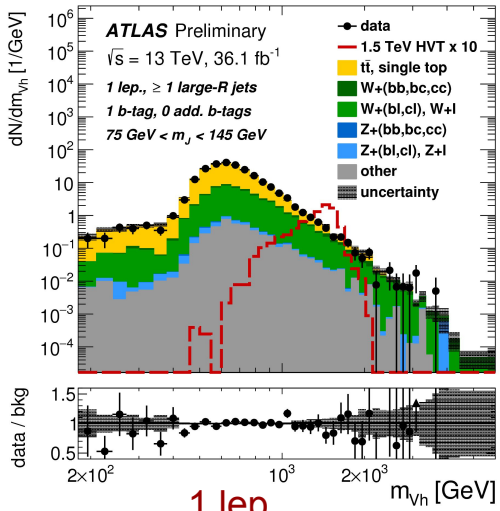
X->VH->vvbb, lvbb, 2l2b

- Different background fraction in each signal region (Background estimation with shape from simulation, normalization from data except mutjet background which use data-driven template)
- Hadron cone base truth labeling template for W/Z + jets

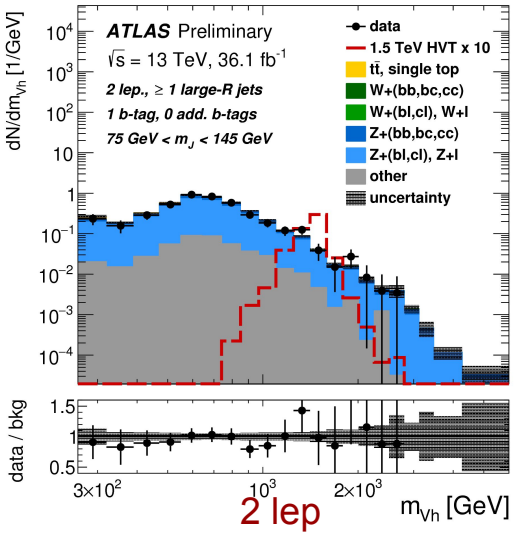
1 btag



0 lep

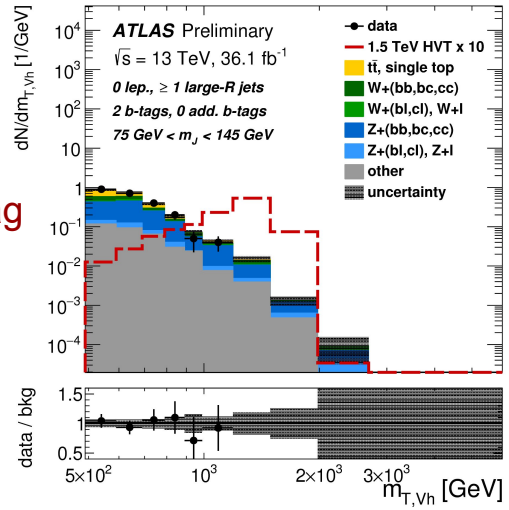


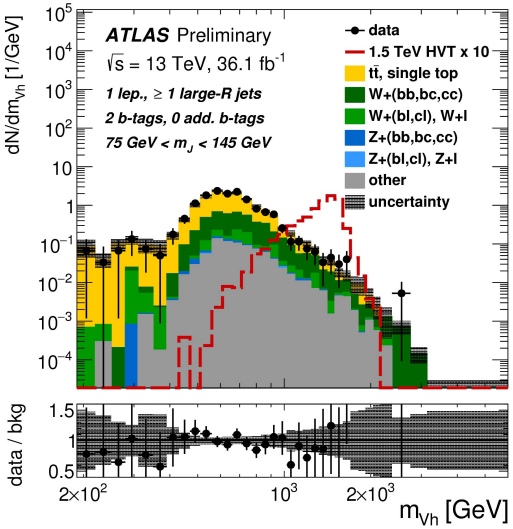
1 lep

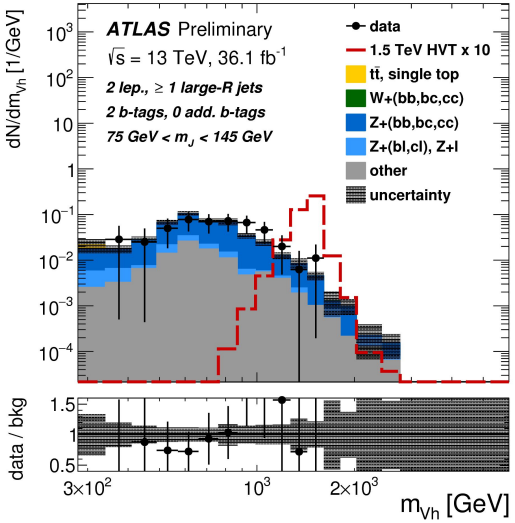


2 lep

2 btag



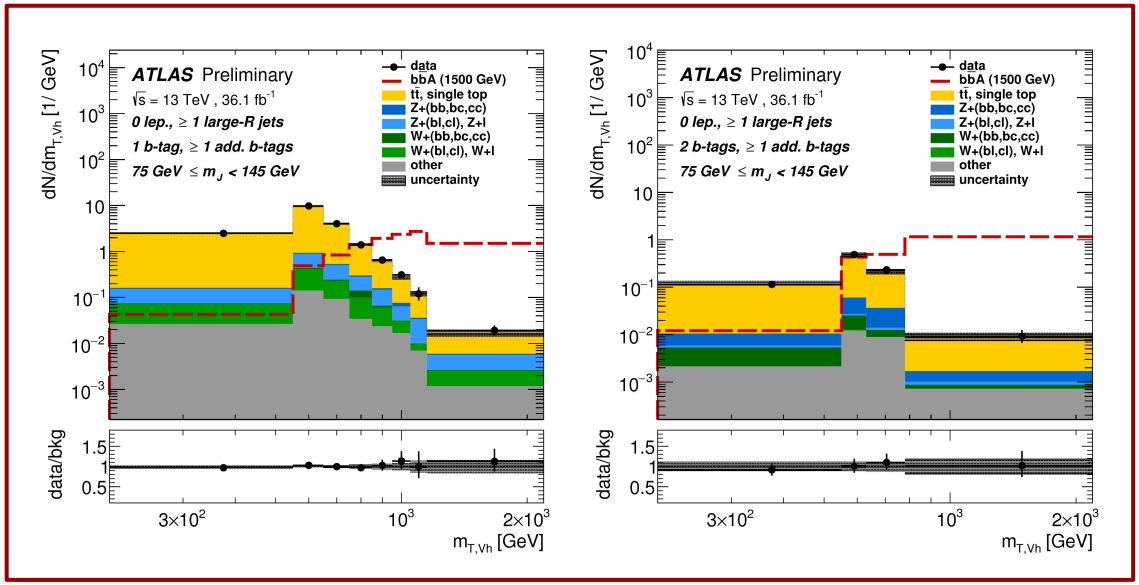




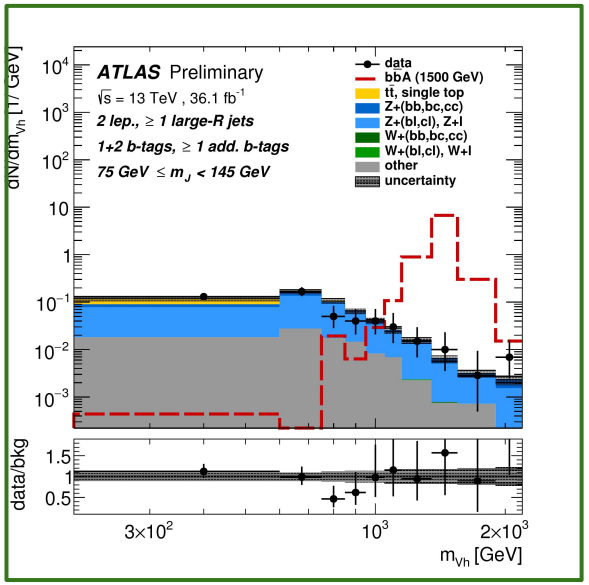
A->ZH->vvbb, 2l2b

- 1,2 b-tag and additional btag 0.4 track jet
  - Combined 1, 2 btag for the 2 lepton channel
- Combined 1, 2 btag for the 2 lepton channel and additional btag 0.4 track jet

0 lep

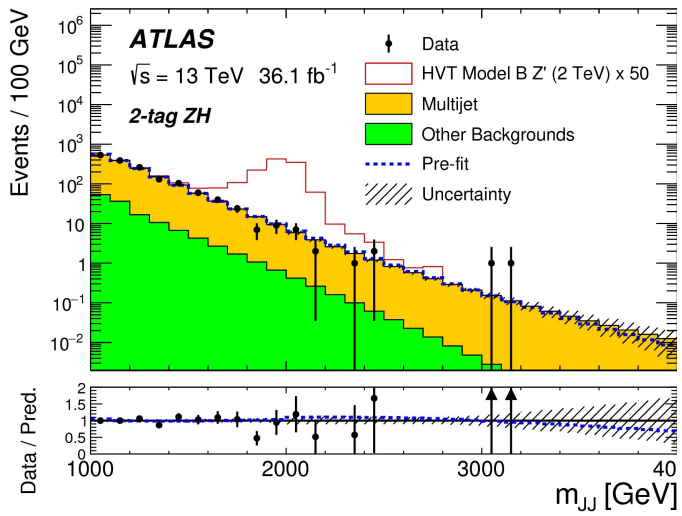


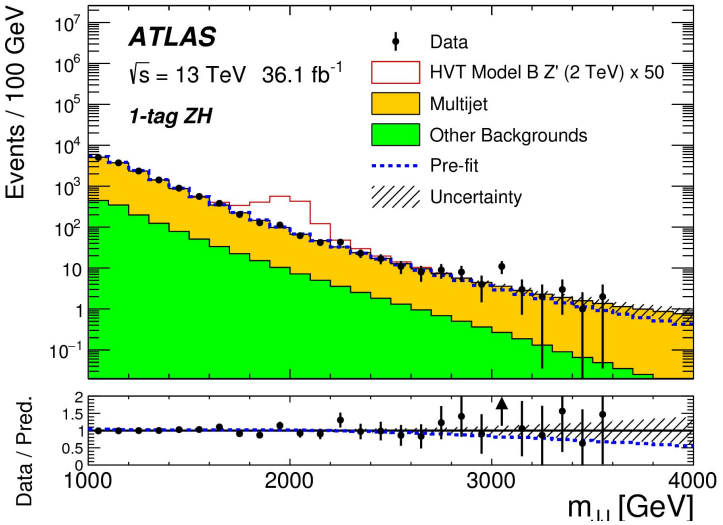
2 lep

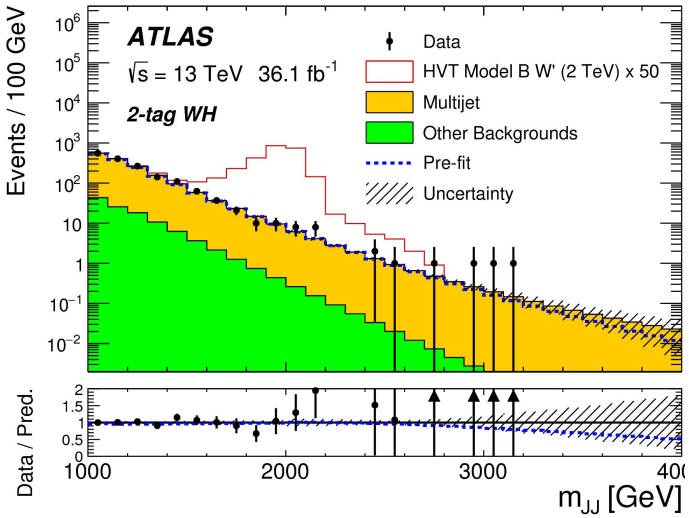


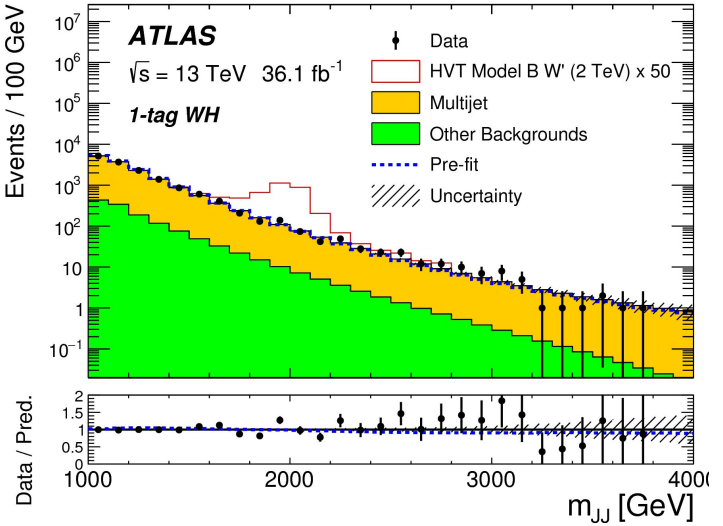
X->VH->qq(‘)bb

Main Background from Mutijet(~ 90%) events is estimated using 0-tag sample and sideband of Higgs mass and vector boson mass





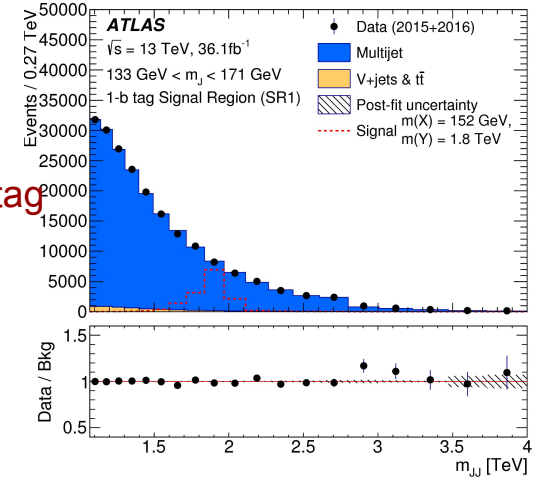




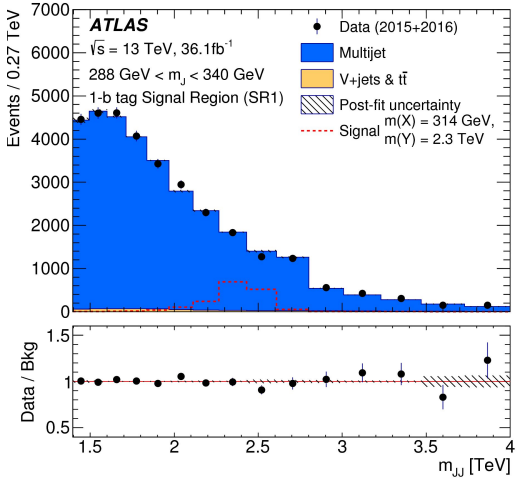
Y-> XH -> qqbb

- Main Background from Mutijet(~ 96%)
- Mutijet background estimated with Higgs jet mass sideband

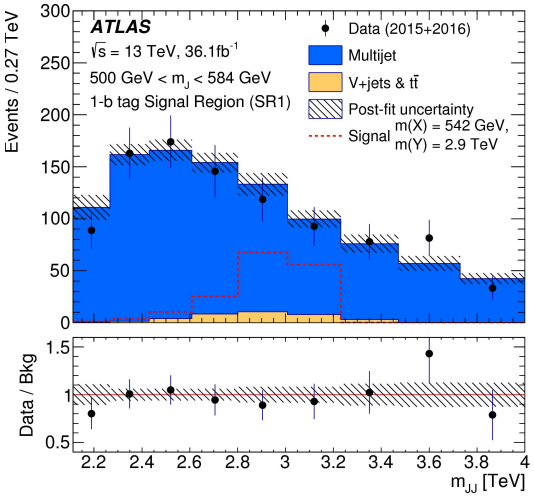
1 btag



133GeV< Mx < 171GeV

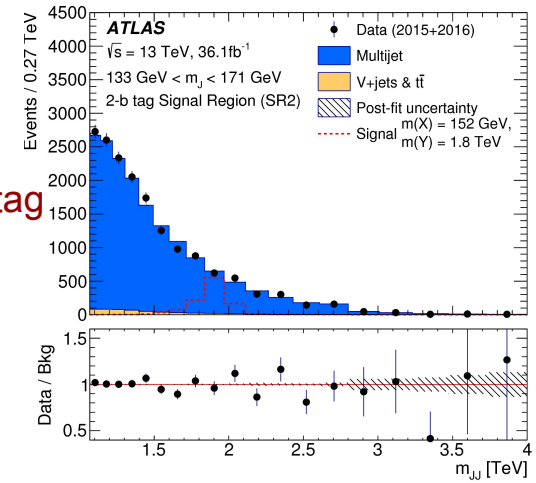


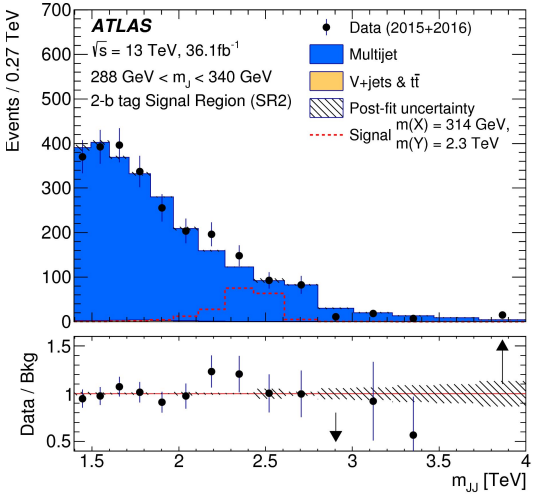
288 GeV < Mx < 340GeV

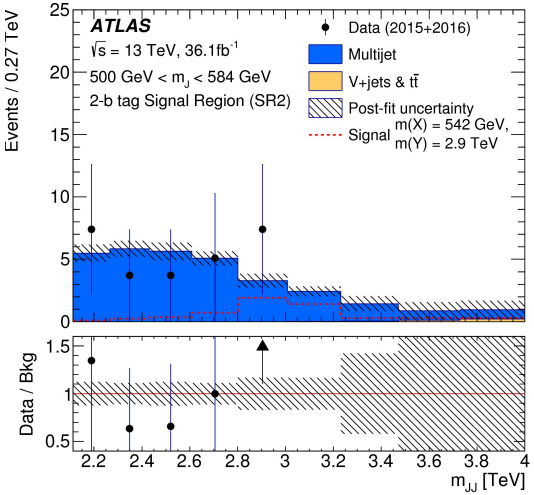


500 < Mx < 584 GeV

2 btag







X->HH->4b

- Data zero tag samples for mutijet (99% purity)

$$N_{\text{bckgrd}}^{n-\text{tag}} = \mu_{\text{multijet}}^{n-\text{tag}} N_{\text{multijet}}^{0-\text{tag}} + \alpha_{t\bar{t}}^{n-\text{tag}} N_{t\bar{t}}^{n-\text{tag}}$$

Bined likelihood in sideband

- Use data sideband region to get normalization factor

$$36\ \text{GeV} < \sqrt{(m_{\text{J}}^{\text{lead}} - 124\ \text{GeV})^2 + (m_{\text{J}}^{\text{subl}} - 115\ \text{GeV})^2} < 63\ \text{GeV}$$