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Bachelor Thesis Presentation

Investigation of systematic uncertainties in the $X \to HH \to b\bar{b}VV^*$ boosted 1-lep analysis

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Supervisors: Stan Lai, Jason Veatch, special thanks to Kira Abeling
II. Institute of Physics (AG Lai)

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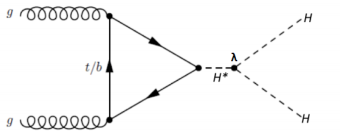
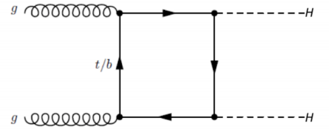
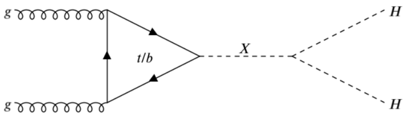
Higgs boson pair production

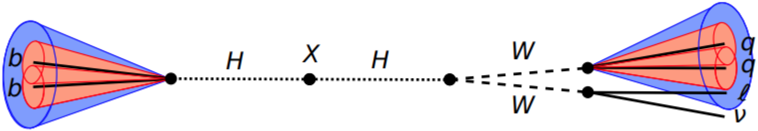
- non-resonant production
  - study of self-coupling λ
  - destructive interference results in small cross section of 31.05 fb in *pp* collisions at 13 TeV





- resonant production
  - heavy resonance X decays into two Higgs bosons
  - cross section is model dependent





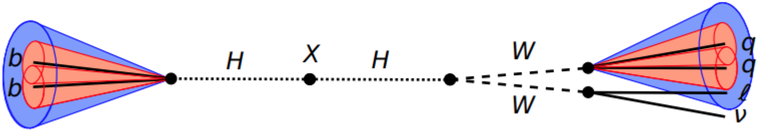
Source: Kira Abeling

Overview

- targets $X \to HH \to b\bar{b}WW^*$ decay channel
- 2nd highest branching ratio 25%
- 1-lepton channel
- boosted topology → use TAR jets

	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0005%

Analysis



Source: Kira Abeling

Event selection

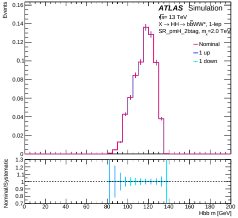
- at least two TAR jets ($p_T > 100\,\text{GeV}$, $|\eta| < 2.0$, $R = 1.0$)
- exactly one TAR jet b-tagged
- electron: $p_T > 10\,\text{GeV}$, $|\eta| < 2.47$ or muon: $p_T > 10\,\text{GeV}$, $|\eta| < 2.5$
- $90\,\text{GeV} < m_{\text{TAR}}^{H \longrightarrow b\bar{b}} < 140\,\text{GeV}$

Systematic Uncertainties

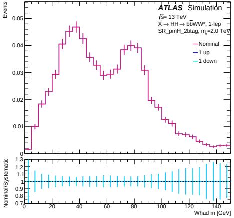
- first part of the thesis work
- systematics are applied in the framework, results in up & down variation
- systematics: electron & muon identification, reconstruction, energy scale & resolution, btagging, jet energy scale & resolution
- made plots to understand impact of systematic uncertainty
- study done on 2 TeV signal and W+jets background sample

Example: JET_CR_JET_Flavor_Composition

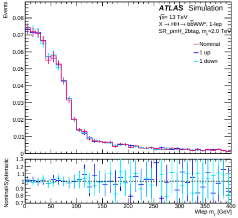
$m_{\mathbf{TAR}}^{H\to b\bar{b}}$



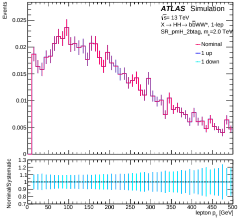
$m_{\mathbf{TAR}}^{W_{\mathbf{had}}}$



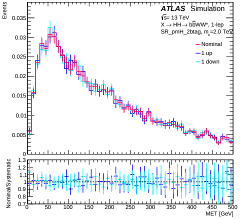
$m_T^{W_{\mathbf{lep}}}$



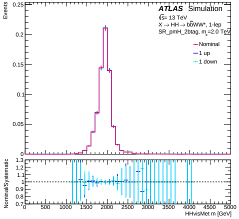
p_T^{ℓ}



$E_T^{\mathbf{miss}}$



$m_{\mathbf{vis+met}}^{HH}$



- 2 TeV signal sample
- jet energy scale uncertainty
- uncertainty on the fractions of gluon and light quark initiated jets
- only small variations

Systematics ranking for final discriminant $m^{HH}_{\mathrm{vis+met}}$

$$\chi^2_\nu = \frac{1}{\nu} \sum_{i=0}^{n} \frac{(O_i - E_i)^2}{\sigma_i^2}$$

Systematic uncertainty	χ^2_ν 1up
jet energy resolution uncertainty (2)	0.250758
jet energy resolution uncertainty (3)	0.168757
jet energy resolution uncertainty (1)	0.1264
jet energy resolution uncertainty (7)	0.116226
jet energy resolution uncertainty (5)	0.0885369
pileup reweighting uncertainty	0.0862512
muon momentum resolution uncertainty (ID)	0.0790913
jet energy resolution uncertainty (4)	0.069321
jet energy scale uncertainty (flavour response)	0.0615696
jet energy scale uncertainty (mixed 1)	0.0614933

(a) 2 TeV signal 1up

Systematic uncertainty	χ^2_ν 1down
jet energy resolution uncertainty (2)	0.250758
jet energy resolution uncertainty (3)	0.168757
jet energy resolution uncertainty (1)	0.1264
jet energy resolution uncertainty (7)	0.116226
jet energy scale uncertainty (mixed 1)	0.0946494
jet energy resolution uncertainty (5)	0.0885369
jet energy resolution uncertainty (4)	0.069321
jet energy scale uncertainty (flavour response)	0.0583546
jet energy resolution uncertainty (6)	0.0533146
pileup reweighting uncertainty	0.0315157

(b) 2 TeV signal 1down

Table 1: Systematic uncertainties ranking for the 1up and 1down variation of the $m^{HH}_{\mathrm{vis+met}}$ distribution for the 2 TeV signal sample.

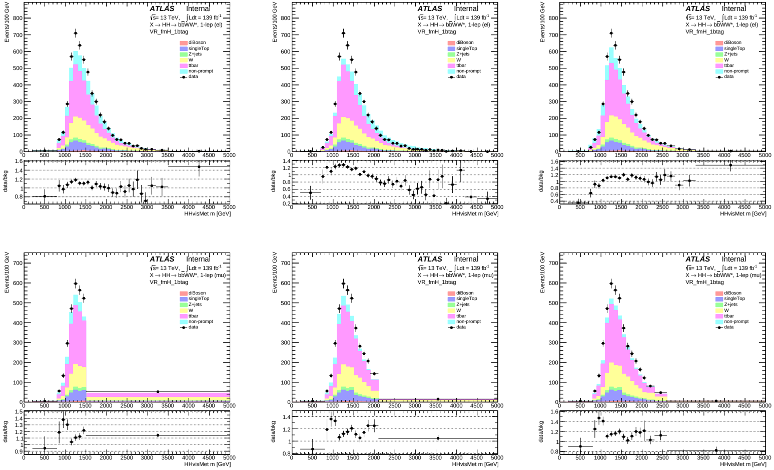
QCD background estimate

- non-prompt lepton background is difficult to model with MC simulation
  → data driven approach
- matrix method uses "loose" and "tight" lepton criteria
- ϵ : fraction of prompt leptons passing the tight selection, measured in MC
  f : fraction of non-prompt leptons passing the tight selection, measured in QCD CR
  binned in: *leadingJetPt, closestJetM, closestJetPt, dR, eta, pt, met, mvismet*
  → event weight: $N^t_{QCD} = \frac{f}{\epsilon - f}(\epsilon - 1)N^t + \frac{f\epsilon}{\epsilon - f}N^{lnt}$

Background estimate

mvismet | leadingJetPt | dR

electron / muon

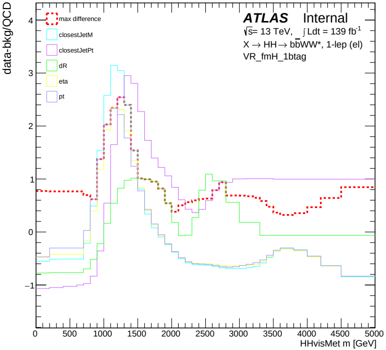


- $m^{HH}_{\text{vis+met}}$ distribution for different QCD estimates
- binning is chosen to ensure each bin contains at least 5 QCD events
- to derive non-closure uncertainty, take difference between data and backgrounds divided by QCD estimate

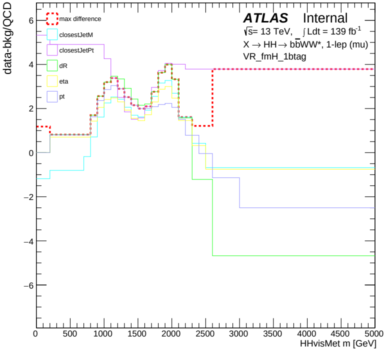
Non-closure uncertainty #2

- uncertainty on the discriminating distribution $m^{HH}_{\text{vis+met}}$
- look at the difference histogram for the $m^{HH}_{\text{vis+met}}$ distributions for the rate binning variables: *closestJetM*, *closestJetPt*, *dR*, *eta*, *pt*
- for each bin take the difference that includes 80 % of the values

Non-closure uncertainty #2



(a) electron



(b) muon

Overlay of the difference histograms for the $m_{\text{vis+met}}^{HH}$ distributions.

Conclusion

- systematic uncertainties in the analysis
  - impact of systematic uncertainties on the shape of the distributions
  - plotbook and systematics ranking
- derivation of non-closure uncertainty for the QCD estimate
  - uncertainty of the method
  - uncertainty of the $m^{HH}_{\mathrm{vis+met}}$ distribution

Thank you for listening!

Back-up

Systematics ranking for final discriminant $m^{HH}_{\text{vis+met}}$

Systematic uncertainty	χ^2_ν 1up
pileup reweighting uncertainty	0.325408
jet energy resolution uncertainty (3)	0.0503201
jet energy resolution uncertainty (4)	0.0497202
jet energy resolution uncertainty (2)	0.0452663
jet energy resolution uncertainty (7)	0.0443334
jet energy resolution uncertainty (5)	0.0433819
jet energy resolution uncertainty (1)	0.0414456
jet energy resolution uncertainty (6)	0.0312831
MET (soft term longitudinal resolution)	0.0238203
jet energy scale uncertainty (flavour response)	0.0200421

(c) W+jets background 1up

Systematic uncertainty	χ^2_ν 1down
pileup reweighting uncertainty	0.134649
jet energy resolution uncertainty (3)	0.0503201
jet energy resolution uncertainty (4)	0.0497202
jet energy resolution uncertainty (2)	0.0452663
jet energy resolution uncertainty (7)	0.0443334
jet energy resolution uncertainty (5)	0.0433819
jet energy resolution uncertainty (1)	0.0414456
jet energy resolution uncertainty (6)	0.0312831
jet energy scale uncertainty (flavour response)	0.0151447
jet energy scale uncertainty (flavour composition)	0.00905725

(d) W+jets background 1down

Table 1: Systematic uncertainties ranking for the 1up and 1down variation of the $m^{HH}_{\text{vis+met}}$ distribution for the W+jets background sample.

Example: PRW_DATASF

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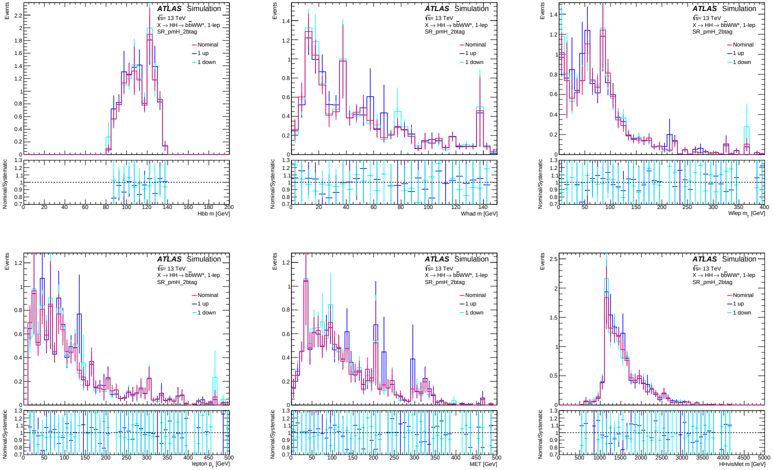
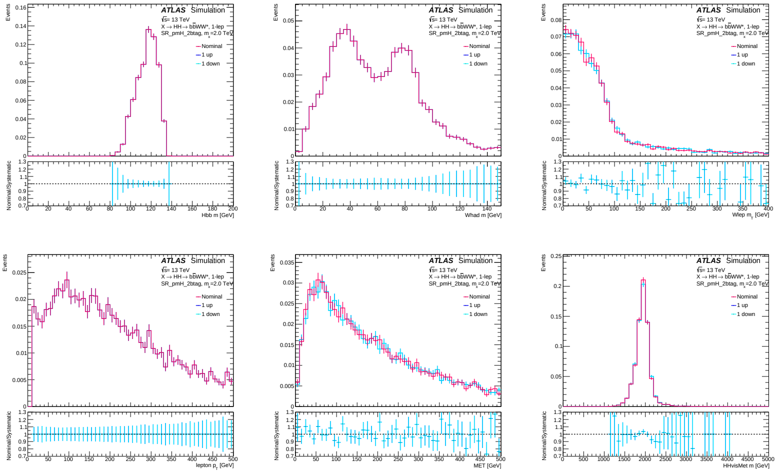


- pileup reweighting uncertainty
- W+jets background process

Example: JET_CR_JET_JER_EffectiveNP_2



- jet energy resolution uncertainty
- 2 TeV signal process

Background estimate (original binning)

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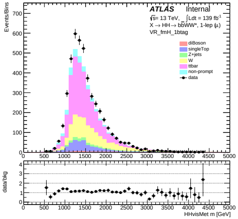
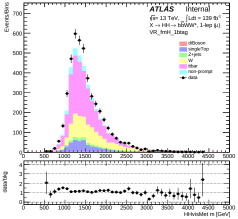
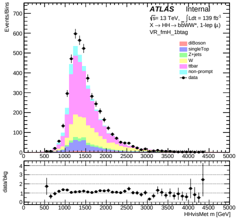
closestJetM (μ)



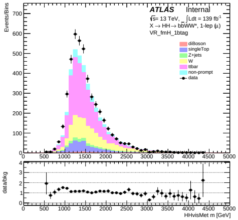
closestJetPt (μ)



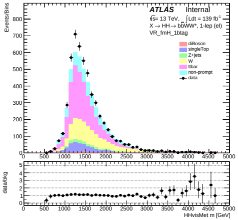
leadingJetPt (μ)



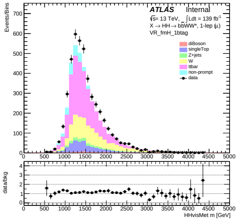
met (μ)



mvismet (el)



mvismet (μ)



- stacked backgrounds and normalised QCD estimates

Difference histograms (original binning)

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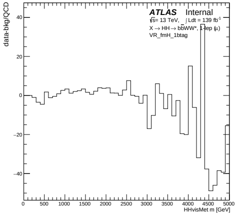
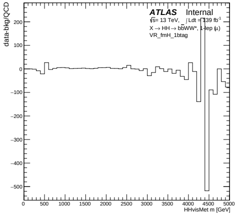
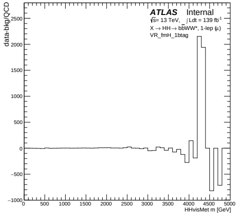
closestJetM (μ)



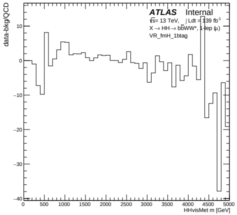
closestJetPt (μ)



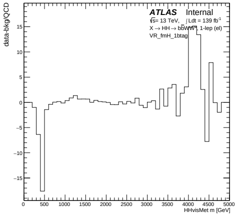
leadingJetPt (μ)



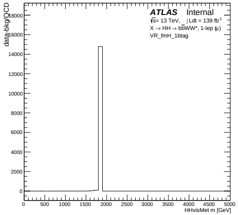
met (μ)



mvismet (el)



mvismet (μ)



- difference between data and background divided by QCD estimate
- some bins with very large differences

  → rebin histograms

Non-closure uncertainty #1

- uncertainty of the method $\longrightarrow$ consider all different rate binning variables
- look at the difference histogram for the distributions that correspond to the rate binning being used, e.g. for the rate binning in closestJetM the $m^{W_{\mathrm{had}}}$ distribution is considered
- take largest absolute bin content for each distribution

Non-closure uncertainty #1

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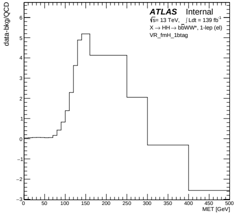
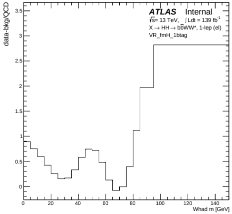
electron

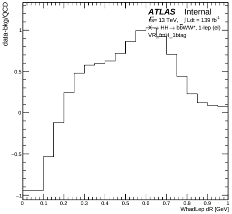
met



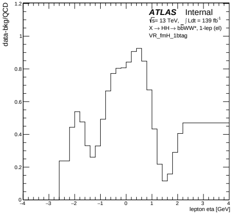
closestJetM



dR

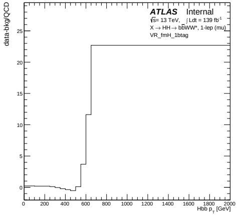


eta

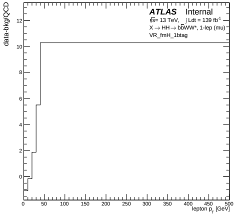


muon

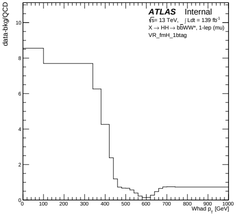
leadingJetPt



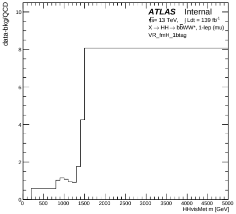
pt



closestJetPt



mvismet



Non-closure uncertainty #2 (all rate binnings)

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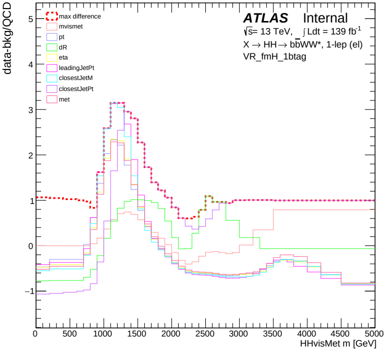
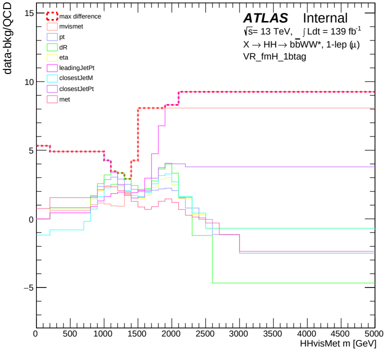


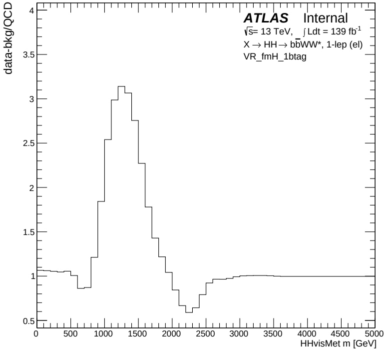
(a) el



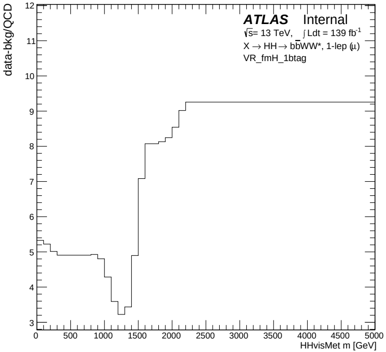
(b) mu

Overlay of the difference histograms for the HHvisMet mass distributions.

Non-closure uncertainty #2 (all rate binnings)



(a) el



(b) mu

Maximum difference taken per bin.