Search for resonant WZ$\rightarrow l\nu l'l'$ Production in the fully leptonic final state in Proton-Proton Collisions at $\sqrt{s} = 13$TeV with the ATLAS Detector

Benjamin Freund

Université de Montréal

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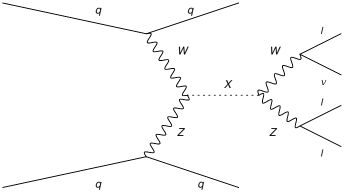
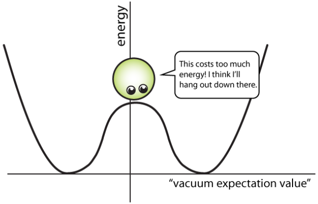
Introduction

- Weak vector boson scattering (VBS) plays a central role in the standard model
- Without the Higgs boson scattering amplitude diverges
- Narrow resonances beyond standard model could help cancellation of divergences

- Key process to study Electroweak Symmetry Breaking mechanism
- Studying qq-fusion and vector boson fusion processes (focus of this talk) with lvll in final states
- Fully leptonic search most sensitive to low mass resonances and to VVX coupling if resonance does not couple to light fermions





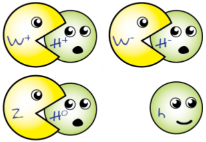
Models - Georgi-Machacek model

Two benchmark models for a scalar and vector resonance with masses between 200 and 900 GeV:

- Scalar: Georgi-Machacek model ($H_5^{\pm}$ →WZ→lvll) [Nuclear Physics B262 (1985) 463-477]
- Vector: Heavy Vector Triplet using Madgraph5 HVT model (vc→WZ→lvll) [arXiv:1402.4431]

Georgi-Machacek model:

- Enlarged Higgs sector (real and complex triplet) less constrained by electro-weak precision measurements
- Model gives Majorana mass to neutrinos
- Predicts ten Higgs bosons, two singlets, a triplet and a quintuplet
- Quintuplet fermiophobic, couples nearly exclusively to vector bosons
- Main parameters: quintuplet mass ($m_5^{\pm}$) and contribution to vev by the complex triplet ($\sin\theta_H$)
- Interaction strength proportional to vev of the triplets



[1]

[1] http://www.quantumdiaries.org/wp-content/

Models - Heavy Vector Triplet

Heavy Vector Triplet:

- Benchmark model which allows to study narrow resonances in a model-independent strategy
- Simplified phenomenological Lagrangian reproducing a large class of models
- Main parameters: coupling to fermions (c_F), couplings to bosons W,Z,H (c_H)
- Here no coupling to fermions is assumed ($c_F = 0$)
- Heavy vector triplet added to the SM

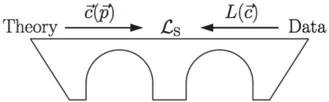
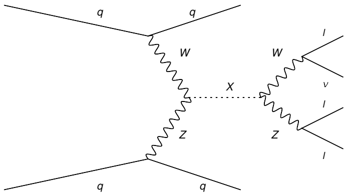


Figure 1.1: Pictorial view of the Bridge Method.

Preselection

- Use 2015-2016 ATLAS pp collision data at 13 TeV with 36 fb^{-1}
- Signature: two forward jets and three leptons
- Exactly three leptons ($p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$) (electrons, muons)
- $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV (neutrino)
- Reconstruct Z-boson candidate: two opposite charged same flavor leptons closest to Z mass and $|m(ll) - m(Z)| < 20$ GeV
- Reconstruct W-boson with third lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$
- Vector boson scattering selection: At least two jets with $p_{\mathrm{T}} > 30$ GeV and $|\eta| < 4.5$



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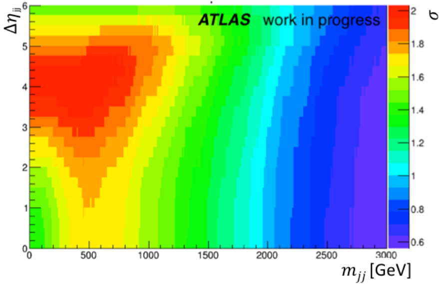
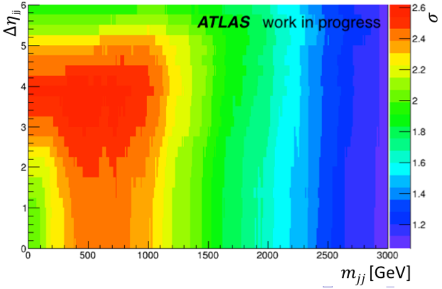
Optimisation of VBS signal region

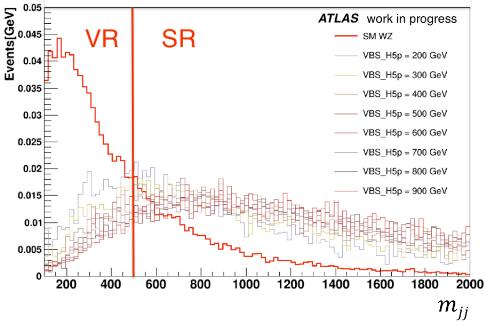
- Select two p_{T}-leading jets as VBS-jets
- Find optimal selection of signal by combining kinematic variables
  - $m_{jj}, \Delta\eta_{jj}$ and $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$
- Maximise binned Poisson significance $\sigma = \sqrt{\sum_i 2(S_i + B_i)\log\left(1 + \frac{S_i}{B_i}\right) - S_i}$
- For simplicity use common selection for all mass points
- 2D-sensitivity scan for m_{jj} and $\Delta\eta_{jj}$ for $H_5^{\pm}$ (left) and W' (right)

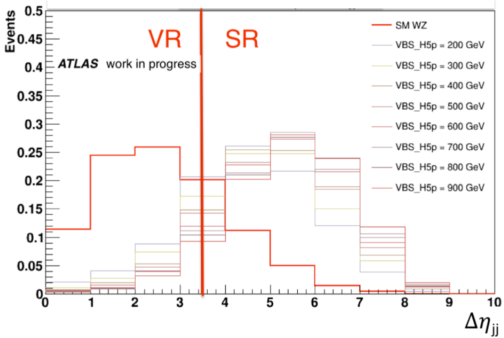




Optimisation of VBS signal region

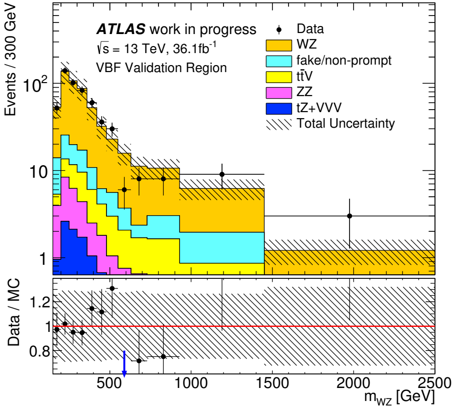
- VBS signal region selection: $m_{jj} > 500$ GeV and $\Delta\eta > 3.5$
- b-jet veto (reduce top background)
- Validation Region orthogonal to signal region:
  - $100 < m_{jj} < 500$ GeV
  - $\Delta\eta < 3.5$



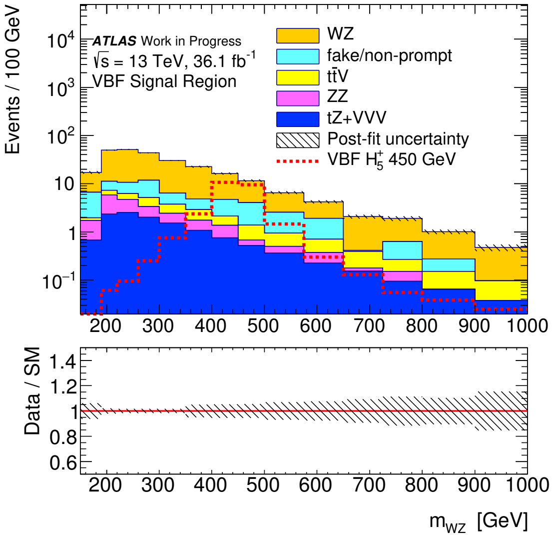


Validation Region

- Standard Model *WZ* dominates background
- All backgrounds obtained from simulation except fake/non-prompt
- Fake/non-prompt background estimated using data driven Method
- Bin size corresponds to experimental resolution
- Good MC/Data agreement in the validation region

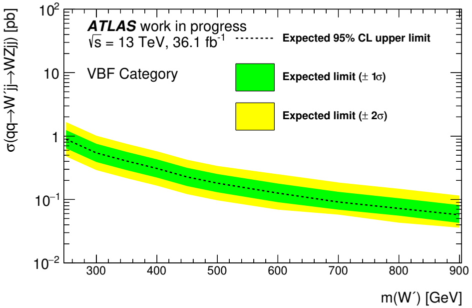


- Not yet published so only showing Monte Carlo expectations



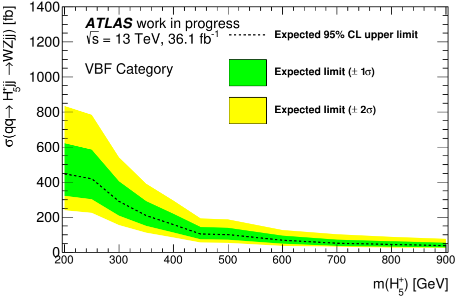
Expected Sensitivity HVT

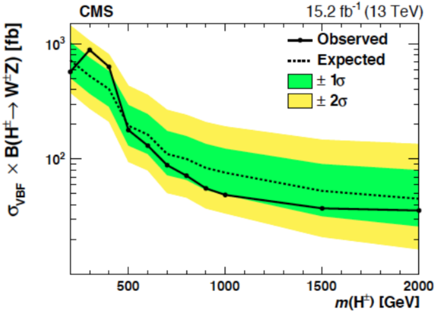
- Expected limits on $\sigma \times \mathrm{BR}(W' \to W^{\pm}Z)$
- Green and yellow bands represent $\pm 1\sigma$ and $\pm 2\sigma$ uncertainty in the expected limits
- HVT model designed for high mass resonances
  - Used here only as benchmark for a vector resonance
  - Limit applies to any vector resonance with width comparable or smaller than experimental resolution



Expected Sensitivity GM and comparison with CMS

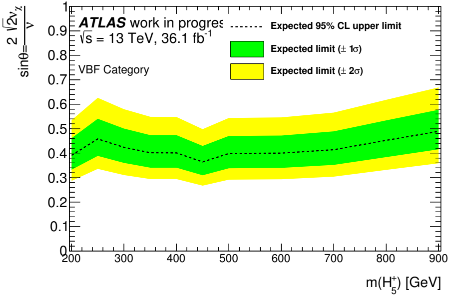
- Expected limits on $\sigma \times \mathrm{BR}(H_5^{\pm} \to W^{\pm} Z)$
- Comparison with CMS run-2 result at 13 TeV with 15.2 fb^{-1} (arXiv:1705.02942 [hep-ex])
- Similar selection but transverse Mass instead of reconstructed invariant mass is used
- Only GM model is tested

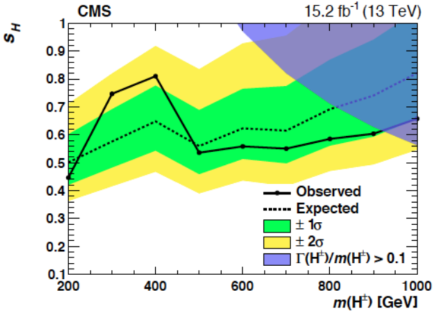




Expected Sensitivity GM and comparison with CMS

- Parameter $\sin(\theta_H)$ of the GM Model as a function of $m_{H_5^\pm}$





- Better sensitivity compared to CMS result (more luminosity and better mass resolution)

Summary and Outlook

- Presented first look at 13 TeV ATLAS *WZ* resonance search
- Results not public yet
- Comparison with CMS results, slightly better sensitivity expected
- Stay tuned for publication

Thank you for your attention.

Backup

Systematics

Table 1: Dominant relative uncertainties in the signal-strength parameter (μ) of hypothesized HVT signal production with $m(W') = 800$ GeV in the $q\bar{q}$ and $m(W') = 450$ GeV in the VBF category, assuming that the production cross sections equal the expected 95% CL upper limits. The impact of the many other sources of systematic uncertainty remains small. The effect of the statistical uncertainty on the signal and background samples is also shown.

qq Category		VBF Gategory	
$m(W') = 800$ GeV		$m(H_5^+) = 450$ GeV	
Source	$\Delta\mu/\mu$ [%]	Source	$\Delta\mu/\mu$ [%]
MC statistical uncertainty	7	WZ modeling : Scale, PDF choice	12
WZ modeling : Scale, PDF choice	5	MC statistical uncertainty	5
Electron identification	5	Jet uncertainty	4
Muon identification	4	Fakes	3
Total systematic uncertainty	12	Total systematic uncertainty	20
Statistical uncertainty	46	Statistical uncertainty	50

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Objects

- Details about event selection and triggers are given in twiki page
- Nominal trigger : use single lepton triggers

Preselected electrons requirements

- Likelihood loose electrons (medium for Z and tight for W)
- ET>25 GeV
- Object Quality requirements
- |z0 sin(theta)| < 0.5
- |d0/σd0| < 5
- Isolation : Working point LooseTrackOnly.

Preselected muons requirements

- Medium muons |η|<2.5
- pT>25 GeV
- d0<1mm cosmic cut
- |z0 sin(theta)| < 0.5
- |d0/σd0| < 3.
- Working point LooseTrackOnly.

Objects

Jets

- AntiKt4TopoEM Jets
- pT >25 GeV and |η|< 2.4 OR pT >30 GeV and 2.4 >|η|< 4.5
- Pileup removal reject jets that have pT<50 GeV, eta<2.4, and JVT<0.64
- Jet Cleaning

Overlap removal

- Use overlap removal tool using preselected leptons
- e-e Electrons (after electron ID cuts) sharing the same ID-track, keep the electron with highest cluster ET
- e-μ Remove CaloTagged muons which share the same Inner Detector track as the electron
- e-jets Removes jets overlapping with electrons with DR < 0.2

ETmiss

- Use METMaker tool (MissingETBase::Source::Track)
- Original MET container MET_Core_AntiKt4EMTopo
- Add electrons, muons after corrections and e-μ and e-e corrections
- Add corrected jets (overlap handle by the tool)
- MET rebuilt adding the "soft term" coming from tracks

WZ Mass

VBS Category

- Request two jets with pT>25 GeV and |η| <4.5 in opposite hemispheres
- Di-jet: two highest pT jets
- mjj >500 GeV and Δηjj >3.5

qq fusion Category

- All the other events that do not satisfy the VBF/VBS criteria will fall in qq fusion category

Reconstruction of WZ mass

- Use x and y component of missing transverse energy, known W mass and four vector of charged lepton assigned to W to estimate pZ of neutrino
- Two solutions exists, take the one with smaller magnitude
- If complex solution take real part
- Using neutrino four-vector to reconstruct W boson
- Invariant mass of WZ calculated using Z and reconstructed W boson

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VBS Opt

- Using MC background
- Optimizing the Poisson significance

$$\sigma = \sqrt{\sum_i 2(S_i + B_i)\log\left(1 + \frac{S_i}{B_i}\right) - S_i}$$

Cut	Min	Max	Steps
m_{jj}	0	1000	50
$d\eta_{jj}$	2.0	6.0	0.1
MET	0	100	10
p_{TC}	0	150	10

- Using square cuts on four variables: m_{jj}, $d\eta_{jj}$, MET and p_{TC} (p_T cut on most central jet if within $|\eta|<2,5$)
- Chose jets with highest p_T
- Optimization code calculates the significance for each possible cut configuration