Resonant Di-Boson Searches with ATLAS and CMS

DIS 2014
Motivation

- How to look for NP in view of hierarchy problem
  - High mass (~TeV)
  - Not seen in EWK precision tests
  - Coupling to massive SM particles (W,Z,t)

\[ X \rightarrow VV \]

- Experimental advantages:
  - W/Z with well known mass → suppress backgrounds
  - Good kinematic reconstruction → reconstruct resonance mass

- Disadvantages:
  - Many different final states → lots of work
  - Resolution suffers in final states with neutrinos
What are we looking for?

Extra Dimensions:
- RS1: traditional benchmark, small BR to VV
- Bulk G: localize SM particles in 5th dim. (bulk)
- Bulk G: large BR to $t\bar{t}$, $V_LV_L$ and HH
- Radion $\rightarrow$ HH

New strong Sector:
- Technicolor
- Little Higgs
- Partial compositeness
- …

More Ideas Welcome
Want to have your model excluded (or found!) ?
Talk to us!
All leptonic final states

- Look for:
  - $Z \rightarrow \text{ee/}\mu\mu,$
  - $Z \rightarrow \nu\nu$
  - $W \rightarrow e\nu/\mu\nu$

- Advantages:
  - Low backgrounds, high purity
  - Kinematic resolution for $ZZ \rightarrow 4l$

- Disadvantages:
  - Low branching fraction
  - Kinematic reconstruction with more than one neutrino
WZ → lllν

- All leptonic final state
  - Only one ν → decent mass resolution
  - very pure
  - Very low BR (~ 1.5%)

- Analysis strategy
  - Select three leptons
  - Compute MWZ from MET and W mass constraint
  - Search for bump in MWZ spectrum
WZ → IIIν limits

- Interpret limits in terms of
  - Sequential SM W' 
  - Heavy vector triplet (weakly coupled resonance and composite Higgs) 
  - Technicolor 

\[ \pi_{TC} \text{ and } \rho_{TC} \text{ masses and BR related} \]
**WW → 2l2ν**

- Compared to WZ:
  - Two ν → poor mass resolution
  - Only two leptons → increased background

- Strategy:
  - Select two leptons (Z veto!)
  - b-veto suppresses top
  - Require MET
  - Study transverse mass of l+l+MET system

- Sensitive to many neutral resonances:
  - RS and bulk Graviton used as benchmark
  - Can be reinterpreted as other narrow resonances
Hadronic Decays

- Look for:
  - Semi-leptonic
  - Fully hadronic

- Advantages:
  - Decent kinematic resolution
  - High branching fractions
  - Access to $H \rightarrow bb$

- Disadvantages:
  - Large backgrounds
  - Somewhat less at very high masses
Reconstruct leptonic Z
- The easy part
- Two leptons, opposite sign, same flavor
- Compatible with Z mass

Reconstruct Hadronic Z
- Tricky: high $p_t$ Z reconstructed as single jet (“merged”)
- Analyze 2 categories → dijet with Z mass → single massive jet

$$\Delta R_{qq} \approx 2 \frac{M_Z}{p_{t,z}}$$
**ZZ → 2l2q**

- Background estimated from $M_{jj/j}$ sidebands
- Dominant syst. uncertainties come from background estimates
- Two ~independent results for dijet and monojet → joint at point of equal exclusion power
Jet sub-structure

- Recluster jet constituents, applying additional conditions at each recombination

\[
z = \frac{\min(p_{T,i},p_{T,j})}{p_{T,jet}} > 0.1 \quad \Delta R < 0.5 \frac{M_{jet}}{p_{T,jet}}
\]
- Filter out soft and large angle QCD emissions

**Mass Drop** *(PRL 100 240001)*
- De-cluster jet by stopping jet algo before last iteration
- Two subjets
- Jet is V-tagged if its mass drop \( \mu_D \) < (analysis dependent) cut value

\[
\mu_D = \frac{M_1}{M_{jet}}
\]

**N-subjettiness** *(JHEP03(2011)015)*
- Topological compatibility with hyp of N subjets
- Recluster jet, halting when N subjets reached
- \( \tau_N \) : \( p_T \)-weighted sum over jet constituents of distances from closest subjet axis

\[
\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \cdot \min(\Delta R_{1,k}, \Delta R_{2,k}, ..., \Delta R_{N,k})
\]

These are NOT THE ONLY POSSIBILITIES! Plenty of alternatives available
check **CMS EXO-13-006**
Control Measurements

- Jet-substructure depends on hadronization models
  - Depends on MC program
  - Decently but not perfectly modeled

- Get Control measurement from data
  - Select semileptonic ttbar events
  - Lepton, MET, bjet
  - Look at opposite hemisphere → high chance for W from t decay
  - Similar to “Tag & Probe” technique

- Extract & Apply correction factors
  - Correct jet mass and cut efficiency
  - Still about 10% uncertainty
  - Application to Z justified by MC
Semileptonic with Substructure

- High $p_t$ lepton reco from Z’ searches
- Standard CMS W reconstruction
- Special treatment for leptons in Z
  - At high boosts, leptons in each others isolation cones $\rightarrow$ subtract!
- Only merged category
  - Using CA8 jets to catch lower $p_t$ W/Z
  - Jet pruning
  - N-subjettiness
- Backgrounds
  - Z+jets for Z channel
  - Also top, WW in W channel
  - Estimate from $M_j$ sideband
Model independent limits

- Nominal Limits in narrow width approximation, restrictive
  
  Solution:
  - Some simplifications to avoid model dependence
  - Extract resolution function from simulation
  - Parameterize Efficiency as function of V kinematics

- Result:
  - Generic limit as function of $M_X$, $\Gamma_X$
  - Estimate model efficiency from published parameterization
  - Test arbitrary model (including WZ)

Read Limit

Apply efficiency parameterization
VV all hadronic

- No leptons, only jets
  - Reduce large backgrounds with substructure variables
  - Somewhat compensated by large signal branching ratio
  - Trigger thresholds quite high

- Analysis Flow:
  - Select two CA8 jets
  - Apply jet-substructure selection
  - Scan $M_{jj}$

- Results:
  - Many possible final states implicit (WW/WZ/ZZ) → many possible signals ($W'$, Graviton…)
VV all hadronic

Jet resolution + efficiency depends on V flavor (W vs Z) an polarization

→ need to check different signal hypothesis separately, even if data remains the same
Follow example of Higgs groups to combine many channels

- Improves exclusion power
- Coherent picture over wider mass range
- Ultimately model-specific
HH→4b

- All hadronic
  - Use btags to suppress QCD background
  - $M_{jj}$ to define signal and control regions

- Selection
  - 4 b-jets, $p_t > 40$ GeV, $|\eta| < 2.5$
  - 2 dijets with $\Delta R < 1.5$, $p_{t,dijet} > 200$ GeV
  - Top veto
  - Signal region in $M_{jj}$ of leading vs subleading dijet

[ATLAS-Conf-2014-005]
HH→4b results

- Background
  - Multijet dominates
  - Use fewer btag samples
  - Use $M_{jj}$ control regions

- Systematic uncertainties dominated by b-tagging uncertainties

- Competitive limits on RS Graviton
  - Losing sensitivity to jet merging at high mass
Outlook: We are not done yet

- Subjet b-tag
  - Especially suitable for H
  - Huge reduction in background

- Explore more final states
  - VH of additional interest
  - Currently not all W/Z final states covered
  - Limit by manpower

- Combine different channels
  - More powerful limits
  - Increases model dependence
  - Requires coordination between analysis groups
Conclusion

- Searches for new physics in diboson push to higher masses
  - Low signal cross section $\rightarrow$ hadronic final states gain importance
  - Developing new techniques to deal with high boosts

- No WW/ZZ/WZ resonance seen
  - SM still standing strong
  - Exclusion limits stronger than ever
  - Many final states probed, but some missing

- Expect more results in Run II
  - Greatly increased reach at 13 TeV
  - Jet-substructure will become more important