Search for resonant WZ Production with the ATLAS detector at the LHC

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Resonance searches are well motivated

- Resonances represent the simplest way to discover new particles
- A statistically significant bump above a smooth background
  - experimentally robust
  - small systematics
  - difficult for unknown backgrounds to mimic
- Model-independent probe to new physics
- Predicted in many beyond SM scenarios with different properties (charge, spin, width, production mechanism)
High mass diboson searches are well motivated

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Resonance benchmarks you will hear about in this talk
- Heavy Vector Triplets or **HVT** (simplified Lagrangian): Model A \( g_V = 1 \) and Model B \( g_V = 3 \)
- Georgi-Machacek (GM) Higgs Triplet Model: \( H^+_5 \)
- Extended gauge model (EGM): with a spin-1 \( W' \) boson
Search strategy

- Choose a WZ decay mode
- Design a selection
- Estimate the background
- Reconstruct invariant mass
- Set limits on BSM theories
WZ decay modes

Hadronic decays:
- Larger branching fractions
- More backgrounds from QCD/multijet events (→ boson tagging!)

Leptonic decays:
- Small branching fractions
- Clean signature, low background

**Fully leptonic decay**
- Experimental signature:
  - 3 high $p_T$, isolated leptons,
  - Missing transverse energy ($E_{T\text{miss}}$)

Backgrounds:
- Non resonant WZ
- Z+jets, Top, Z+γ, ZZ, and VVV
Search strategy

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- Design a selection
WZ object and event selection

**Motivation:**

- High efficiency 3 leptons in final state
- Reduce background from jet, Z+jet, QCD, tt and single top
- Reduce ZZ background
- Reduce non peaking backgrounds like tt and single top, WW+jets
- Reduce the Z+jets and Top background
- To account for the W and reduce Z+jets

**Single lepton trigger**

- High $p_T$ leptons ($p_T > 25$ GeV) in detector acceptance
- Leptons must come from primary vertex. Impact parameter cuts $|d_0/\sigma_{d_0}|$
- Calorimeter and track isolation used
- Only 3 good leptons (additional 20 GeV leptons)
- Pair of same flavor, opposite sign, high $p_T$ isolated leptons. Consistent with a Z boson in a $\pm 20$ GeV window.
- If more than one pair, select the closest to Z mass

**Additional tight lepton requirement**

- $E_T^{\text{miss}} > 25$ GeV
Signal optimization

- Improve the sensitivity to resonant signals, some additional selections can be added, for example:
  - $\Delta y(W, Z) < 1.5 \rightarrow$ remove SM background
  - $\Delta \phi(\ell, E_{T}^{\text{miss}})$ is used to define 2 signal regions (SR)
    - Low Mass SR: $\Delta \phi(\ell, E_{T}^{\text{miss}}) < 1.5$
    - High Mass SR: $\Delta \phi(\ell, E_{T}^{\text{miss}}) > 1.5$

ATLAS 8 TeV

$\Delta y(W, Z)$

Data/Bkg

Events / 0.2

$\Delta \phi(\ell, E_{T}^{\text{miss}})$

ATLAS

$\sqrt{s} = 8 \text{ TeV}, \int L dt = 20.3 \text{ fb}^{-1}$

$E_{T}^{\text{miss}} > 25 \text{ GeV}: \text{All channels combined}$

$\Delta y(W, Z) < 1.5$: All channels combined
Signal optimization

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  - $L_T$ the scalar sum of the leptons $p_T$ cut value changing depending on $m_{WZ}$

arXiv:1407.3476
Signal optimization

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- Some additional selections can be added, for example:
  - $\Delta y(W, Z) < 1.5 \rightarrow$ remove SM background
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  - $L_T$ the scalar sum of the leptons $p_T$ cut value changing depending on $m_{WZ}$
  - The ratio between the boson $p_T$ and the $m_{WZ}$ mass
    - $p_T^W / m_{WZ}$ and $p_T^Z / m_{WZ}$
Search strategy

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- Estimate the background
Background estimation

- Accurate background estimate to not bias signal extraction
- Two techniques
  - background shape from simulation and normalize in control region + theory/experimental systematic
  - ex. ATLAS WZ control region:
    - $\Delta y(W, Z)$ requirement reversed $\rightarrow$ reduce signal contamination
    - $\Delta \phi(\ell, E_{\text{miss}})$ is removed

arXiv:1406.4456
Background estimation

- Accurate background estimate to not bias signal extraction

- Two techniques

  - background shape from simulation and normalize in control region + theory/experimental systematic

  - parameterize the background shape and fit directly on data

    - ex. ATLAS 8 TeV to estimate the background at high mass analysis 2 fits were performed
      1. WZ bkg with \( m_{WZ} > 500 \text{ GeV} \)
      2. non-WZ bkg with \( m_{WZ} > 300 \text{ GeV} \)

    - The power-law function \( N(x) = c_0 x^{c_1} \), where \( x \) is \( m_{WZ} \)
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Mass reconstruction

- Mass reconstruction and resolution crucial in resonance searches
  - statistical power inversely proportional to the mass resolution
  - resonance hidden by bad understanding of resolution

- Need ad-hoc studies and calibration strategies at such large momenta
Mass reconstruction

- Mass reconstruction and resolution crucial in resonance searches
  - Statistical power inversely proportional to the mass resolution
  - Resonance hidden by bad understanding of resolution
- In the $X \rightarrow WZ \rightarrow \ell\nu\ell\ell$ channel the incomplete invariant mass reconstruction due to the missing neutrino the $p_Z$ information
  - Use the $\ell\nu\ell\ell$ transverse mass information
    - Ex. CMS result at 13 TeV for the $H^+_{5}$

arXiv:1705.02942
Mass reconstruction

- Mass reconstruction and resolution crucial in resonance searches
  - statistical power inversely proportional to the mass resolution
  - resonance hidden by bad understanding of resolution

- In the $X \rightarrow WZ \rightarrow \ell\nu\ell\ell$ channel the complete invariant mass reconstruction is not possible due to the missing neutrino the $p_Z$ information
  - Use the $\ell\nu\ell\ell$ transverse mass information
  - Assume a W on-shell and solve the equation to obtain the neutrino $p_Z$ information
    - several solutions are possible → optimization based on resolution (~10% at 1 TeV)
8 TeV Results

Low Mass signal region

High Mass signal region

Low Mass SR: $\Delta \phi(\ell, E_{T}^{miss})<1.5$

High Mass SR: $\Delta \phi(\ell, E_{T}^{miss})>1.5$

arXiv:1406.4456
Choose a WZ decay mode

Design a selection

Estimate the background

Reconstruct invariant mass

Set limits on BSM theories
Limits on BSM theories

- Limits are extracted by using a binned Fit of the WZ invariant mass shape
  - All lepton decay are combined
  - The systematics uncertainties are included in the fit being the SM WZ background the dominant one

- For $m < 400$ GeV, the two SR are combined to maximize the sensitivity of the search. For $m > 400$ GeV, only the High Mass SR is used.

A mass limit of 1.52 TeV is derived for the $W'$
The 13 TeV big picture

\[ \sigma(pp \to W^+ W^-) \text{ [pb]} \]

ATLAS Preliminary
\( \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \)

95% C.L. exclusion limits

- HVT model B \( g_v = 3 \)
- Observed
- Expected
- qqqq
- lvqq
- llqq
- vvqq

lvll, llqq
- Low mass region \( \to \) good resolution
- High mass region \( \to \) statistically limited

lvqq
- Good sensitivity in wide mass region

vvqq:
- Low mass region \( \to \) bad mass resolution
- High mass region \( \to \) high statistics

qqqq:
- Low mass \( \to \) QCD background
- High mass \( \to \) Jet related uncertainties

ATLAS exotics public results
Summary

- Search for heavy resonances in the dibosons channels is one of the most direct ways to find new physics
- New results and more Run-2 data are coming! Stay tune…
Backup