Search for New Phenomena with Dijets @ ATLAS

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Introduction

- Beyond Standard Model (BSM) physics predicts new resonances decay to a pair of objects
  - Di (b)-jet final states with or without associated ISR object
  - Dark Matter mediators may show as a resonance in SM particles

- Standard Model background processes produce smoothly falling invariant mass spectra
  - Look for narrow peak signal
  - Model background with parametric function from data

- Searches:
  - Model independent analyses
  - Limits on specific models
**Experimental ingredients**

- Select final state and resonance mass range
  - Low mass or high mass in these cases

- Look for appropriate trigger and physical objects, select events in unbiased way
  - Small-R jets (resolved topologies) / large-R jets (boosted topologies)

- Estimate background and systematic variations to be used as nuisance parameters in a fit
  - MC statistically limited due to high rate for these final states
  - Data-driven background estimation, brings challenges when fitting high statistics distributions

- Use favorite peak searching algorithm on invariant masses
  - Narrow or wide resonances
  - Global fit challenging, sliding window methods
  - Local significance of a peak. Set limits if no significant peak found

- Compare to simulated signal and put limits on specific models. One dimensional vs mass or two dimensional (coupling-mass plane)
  - 95% CL limits on $\sigma \times \text{BR}$
Search for low-mass resonances decaying into two jets and produced in association with a photon using $pp$ collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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Dijet resonances at low mass

- 2015 + 2016 + 2017 data
- Flavor inclusive and 2-btag selections
- SM dijet suppression with $y^* < 0.75$

- Trigger on radiated photon to circumvent trigger limitations and explore the low invariant mass region
  - Single-$\gamma$ trigger for $M_{jj} < 450$ GeV
  - $\gamma$+2-jets trigger for $M_{jj} > 450$ GeV

arXiv:1901.10917
Dijet resonances at low mass

- **SWIFt (sliding windows) background estimate**
  - Choose a “standard” function
  - select a window width around each bin
  - Use largest possible width with a fit p-value > 0.5
  - repeat for each bin
  - Choose function with largest p-value (3-5 parameters)
  - Function with lowest $\chi^2$ (with p-value>0.05) as systematic estimate

\[ f(x) = p_1 (1 - x)^p_2 x^p_3 + p_4 \ln x + p_5 (\ln x)^2 \]
Dijet resonances at low mass

- Excluded values of the coupling between a $Z'$ and quarks @ 95% CL
- 2 b-tag selection sensitive to models with enhanced couplings to heavy quarks, slightly better sensitivity than flavor-inclusive couplings
Dijet resonances at low mass

- Upper limits on Gaussian-shape contributions to the dijet mass distributions
- Limits on intrinsically narrow contributions with Gaussian mass resolution ranging from 8% to 3%

arXiv:1901.10917
Search for New Phenomena in Dijet Events using 139 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 13$ TeV collected with the ATLAS Detector

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Dijet resonances at high mass

- Searches for BSM signals at high masses (large fraction of collision energy)
- Smoothly falling (QCD) dijet invariant mass spectrum
- New resonant state may appear as localized excess (probe high mass region)

**ATLAS - CONF-2019-007**

- **Full Run2 data (139 fb⁻¹)**
  - Single jet trigger requirement \( p_T^{\text{lead-jet}} > 420 \text{ GeV} \)
  - Low end mass range determined by trigger threshold
  - \( y^* < 0.6 \) (reduce QCD)
- Variable binning accounting for detector resolution
- Background estimate with SWIFt
  - 4-parameter fit function
- Look for localized excesses with BumpHunter
Dijet resonances at high mass

- Searches for BSM signals at high masses
- Smoothly falling (QCD) dijet invariant mass spectrum
- New resonant state may appear as localized excess

ATLAS Preliminary

\( \sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1} \)

- Data
- Background fit
- BumpHunter interpo.

\( q^*, m_q = 4.0 \text{ TeV} \)
\( q^*, m_q = 5.0 \text{ TeV} \)

- Variable binning accounting for detector resolution
- Background estimate with SWIfT
  - 4-parameter function fit
- Look for localized excesses with BumpHunter
Dijet resonances at high mass

- Benchmark model $q^*$ excluded up to 6.7 TeV
- Search also for generic Gaussian shaped signals with different widths
  - (excluded up to 6 TeV)
(boosted) $b\bar{b}$ low mass resonances

Search for boosted resonances decaying to two $b$-quarks and produced in association with a jet at $\sqrt{s} = 13$ TeV with the ATLAS detector

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Search for dark matter through boosted decays to $b\bar{b}$ + ISR jet / photon
- ISR trigger event allowing low mass mediator search

Sensitive to new mediators with Higgs-like couplings through $X \rightarrow bb$ decays
- Benchmark $Z'$ model with democratic couplings

Signature: two large-R jets (1 b-tagged)

Many choices in reconstructing large-R jets
- **radius**: increasing containment of signal
- **Grooming**: remove pile-up cluster and soft radiation
- **Use of tracking information**: better angular resolution for substructure
bb low mass resonances

- Search for new physics with model-independent tools
  - SWIFt + BumpHunter
  - Model quite consistent with data (BH p-value = 0.54)
**bb** low mass resonances

- Axial Z’ exclusion limits translated into limits function of the DM coupling

![Graph showing Axial Z’ exclusion limits](image)

**ATLAS**

ATLAS-CONF-2018-052
**V+jets** μ measurement: 5 σ significance

\[ \mu_V = 1.5 \pm 0.22 \pm 0.29/0.25 \text{ (syst.)} \pm 0.18 \text{ (th.)} \]

**H+jets** μ measurement: 1.6 σ significance

\[ \mu_H = 5.8 \pm 3.1 \text{ (stat.)} \pm 1.9 \text{ (syst.)} \pm 1.3 \text{ (th.)} \]
Dijet search status

Dijet search contours for 95% CL upper limits on the coupling $g_q$ as a function of the resonance mass $m_{Z'}$ for the leptophobic axial-vector $Z'$ model

$\sqrt{s} = 13$ TeV, 3.6-37.0 fb$^{-1}$

ATLAS

(Preliminary) Di-b-jet trigger

Jet trigger

Axial vector mediator
Dirac DM
$m_X = 10$ TeV, $g_X = 1.0$

$|y_{12}| < 0.3$

$|y_{12}| < 0.6$

95% CL upper limits
- Observed
- Expected

Dijet 8 TeV
20.3 fb$^{-1}$

Boosted dijet + ISR
38.1 fb$^{-1}$
arXiv:1801.05769

Resolved dijet + ISR ($\gamma$)
Preliminary, 15.5 fb$^{-1}$
ATLAS-CONF-2016-070

Resolved dijet + ISR ($j$)
Preliminary, 15.5 fb$^{-1}$
ATLAS-CONF-2016-070

Dijet
24.3 & 36.1 fb$^{-1}$

Dijet TLA
3.6 & 20.7 fb$^{-1}$

$t\bar{t}$ resonances
36.1 fb$^{-1}$

Dijet
37.2 fb$^{-1}$

Dijet angular
37.0 fb$^{-1}$
Conclusions

- Search for new resonances is a key goal of LHC experiments

- New results in BSM resonances searches decaying to a pair of SM objects
  - No excesses in ATLAS data so far
  - Constraints in several benchmark models

- Significant improvements due to
  - increased datasets (full Run 2)
  - Better understanding of detectors, better triggers and object definitions
  - Boosted and resolved topologies
  - Sensitivity to heavy quarks couplings
  - Improved background model and fitting techniques
  - Unexpected findings can be around the corner!
Back Up
**SWIFt (sliding windows) background estimate**

- Choose a “standard” function
- Select a window width around each bin
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- Repeat for each bin
- Choose function with largest p-value (3-5 parameters)
- Function with lowest p-value as systematic estimate

\[ f(x) = p_1 (1 - x)^{p_2} x^{p_3} + p_4 \ln x + p_5 (\ln x)^2 \]
Signal injection test: test robustness of background estimation method within the search phase. The test demonstrates that the presence of a nearly detectable signal, namely one with a signal strength slightly below the threshold needed by the BumpHunter algorithm to trigger exclusion of the corresponding mjj window from the fit range, does not significantly change the background estimation with respect to the background-only case.
**Event classification**
- Signal and validation regions defined based on number of b-tagged sub-jets
- Predict flavor composition of dijet background in the SR

**Dijet background**
- Modeled with exponential polynomials
- Found to be unbiased in SR and CR within the search region
Dijet resonances with an isolated lepton

Search for dijet resonances in events with an isolated lepton using $\sqrt{s} = 13$ TeV proton–proton collision data collected by the ATLAS detector

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Dijet resonances with a lepton

- New experimental signature
- Use single electron or muon trigger to extend $m_{jj}$ region below 1 TeV
- Background model based on 5 parameter fit function and SWIFt

Limits on BSM signal approximated by Gaussian contributions of various widths