Searches with boosted objects at ATLAS and CMS

Dermot Moran (CIEMAT)
On behalf of the ATLAS and CMS collaborations
Why is the Higgs boson mass so low?

Some candidates to solve the Hierarchy problem:

- **SUSY**: A new symmetry protects the higgs mass
- **Composite Higgs**: Higgs is a bound state of new strong interaction
- **Warped Extra Dimensions**: Fundamental Planck mass is small

All suggest new particles with decays involving $V/h/top$
V/h/t hadronic decays have large BRs

If **boosted** (heavy X, ISR) decay products are collimated

Use **large radius anti-\(K_t\) jets** (\(R=0.8\) at CMS and \(R=1.0\) at ATLAS)

With **substructure techniques** to tag boosted signal jets
Jet Grooming removes soft radiation (push QCD $m_J \rightarrow 0$)

- **Softdrop at CMS**: CA decluster requiring subjets with $P_T / P_T^J > 10\%$ → with PUPPI pileup mitigation

- **Trimming at ATLAS**: $K_t$ Recluster into subjets requiring $P_T / P_T^J > 5\%$ → Improved resolution at high $P_T$ with track-assisted mass

- **Typically use $m_J$** to define **SR and SB**

---

**EXOT-2017-01**

**ATLAS**

- $\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$
- W/Z validation

Jet channel

- **Data**
- **W + jets**
- **Z + jets**
- **Background est.**
- **Bkg. stat. uncert.**
- **Bkg. syst. uncert.**

**Large-$R$ jet mass [GeV]**

- **SR**

**Events / 2 GeV**

- **Data - background est.**

Dermot Moran (CIEMAT)

March 20, 2018
Substructure discriminants (Many on the market!!)

- **N-subjettiness** $\tau_N \to$ Quantify to what extent constituents are aligned along N subjet axes
  - $\tau_2/\tau_1$ used to ID 2 subjets: V tagging
  - $\tau_3/\tau_2$ used to ID 3 subjets: top tagging

- **Ratio of Energy Correlation functions** $D_2$ also used for V tagging

- **b-tagging** used for ID of $h(b\bar{b})$, $Z(b\bar{b})$

---

**PAS-B2G-17-013**

$X \to ZV \to llqq$

\[ 35.9 \text{ fb}^{-1} (13 \text{ TeV}) \]

**CMS Preliminary**

- Data
- $Z(\ell\ell) + \text{jets}$
- $tW$ WW
- $ZV$
- Bkg. unc.
- $m_X = 600 \text{ GeV}$
- $G \to Z(ll)Z(qq)$
- $\tilde{k} = 0.5 (\sigma \times 5)$

---

**Dermot Moran (CIEMAT)**
Typically perform search using invariant mass of High $P_T$ objects

Narrow width approximation

Will show latest results with boosted $V/h/qq$ using 2016 and 2015 datasets!

For results with boosted tops see Julie Hogan's Talk
\[ X \rightarrow Z(\ell\ell) V \] (low and high mass) search at CMS PAS-B2G-17-013

- \( V \) reco with 2 small-R jets or 1 large-R jet
- Categorized based on \( \tau_{21} \) (high mass) and b-tagging (low mass)
- \( Z+\text{Jets} \) estimate: fit data in SB and apply \( \alpha \left( \frac{Z+\text{Jets}^{SR}_{MC}}{Z+\text{Jets}^{SB}_{MC}} \right) \) ratio (high mass)
- NLO simulation with uncertainties from data-MC comparisons in SB (low mass)

ATLAS analysis targeting same final state EXOT-2016-29
**X → V(νν, ℓν, ℓℓ)hz(bb̅) search at CMS PAS-B2G-17-004**

- **h(bb̅) reconstruction with high** $P_T$ **large-R jet → Use b-tagging of subjets**
- **Categorized by multiplicity of Leptons and large-R jet b-tags**
- **W/Z+Jets estimates from $\alpha$ method (top normalisation from CR)**

---

**Dermot Moran (CIEMAT) March 20, 2018 8 / 20**
\( X \rightarrow V(\nu\nu, \ell\nu, \ell\ell)h(b\bar{b}) \) search at CMS

2HDM and \( Z' \)-2HDM interpretations

\[
\begin{align*}
A_0 \rightarrow \text{Zh} \rightarrow A_0 l, 2l \text{ categories} & \\
\text{Observed} & \\
\text{Median expected} & \\
\text{95\% expected} & \\
\text{Expected} & \\
\pm 1 \text{ std. deviation} & \\
\pm 2 \text{ std. deviation} & \\
\text{95\% CL upper limit on } \sigma(Z) & \text{B}(Z \rightarrow A_0h(b\bar{b})) \text{ (fb)}
\end{align*}
\]

Dermot Moran (CIEMAT)

March 20, 2018 9 / 20
\(X \rightarrow V(\nu\nu, \ell\nu, \ell\ell)h(b\bar{b})\) search at ATLAS EXOT-2016-10

- \(h(b\bar{b})\) reconstruction with 2 small-R jets or 1 large-R jet
- Categorized by multiplicity of Leptons, \(h\) b-tags and associated jets with b-tags (sensitive to \(b\bar{b}A\) associated production)
- Top and \(W/Z+\)Jets estimates from simulation (normalised to data)
Heavy Vector Triplet $W'$ (Spin 1) and 2HDM A (Spin 0) interpretations

Mild excess around 440 GeV in bbA search (3.6σ local, 2.4σ global)
Bulk Graviton (Spin 2) and Heavy Vector Triplet $W'$ (Spin 1) interpretations

Summary of ATLAS DiBoson Limits can be found in Carl Gwilliam's talk
Light $X \rightarrow q\bar{q}$ with ISR search at ATLAS

- High $P_T$ photon or jet (ISR) and large R Jet
- Use $\tau_{21}$ decorrelated from $m_J$ with $\rho = \log\left(\frac{m_J^2}{P_T}\right) \rightarrow$ Easier to model $m_J$
- MultiJet and $\gamma + jet$ bin-by-bin estimate from $\tau_{21}^{fail}$ CR using $TF = \tau_{21}^{pass} / \tau_{21}^{fail}$ measured in $m_J$ SB
Jet and photon channels combined

Observed 95% CL limit
Expected 95% CL limit

2.4σ deviation at 140 GeV (1.2σ global)
CMS analysis targeting same final state EXO-17-001
SUSY $\tilde{g}$ search with $h(b\bar{b}) + \text{MET}$ at CMS SUS-17-006

- Large-R Jet is $h$ tagged with double-$b$ algorithm (MVA with track, vertex and substructure info)
- Categorized by multiplicity of $h$ tags and MET
- Background estimate by extrapolation from 0$h$ CR and $m_J$ SB to SR

**ATLAS analysis targeting same final state EXOT-2016-25**
Main observable is sum of $M_J$ of the 4 leading high $P_T$ large-R Jets: $M_J^{\sum}$

Categorization using $M_J^{\sum}$, $\Delta \eta (J1, J2)$, Jet multiplicity and b-tagging (significant b and t content)

QCD shape estimate using Jet mass PDFs from CR
Cascade decay (involving $\tilde{\chi}_1^0$) and direct decay ($\tilde{g} \rightarrow qqq$) interpretations

For RPV SUSY results with boosted objects at CMS see Claudia Seitz's Talk
Consider $q\bar{q} \to W^* \to N\ell$ (DY) and $q\gamma \to N\ell q$ ($W\gamma$ fusion) production

SS dilepton + small-R jets or large-R jet ($W$-tagged with $\tau_{21}$)

Mis-ID lepton probabilities estimated using dijet tag-and-probe

Optimised selection for each signal hypothesis (20 to 1600 GeV)
Majorana Neutrino search limits

limits on heavy neutrino and SM neutrino mixing matrix elements

- **CMS Preliminary**
  - 95% CL upper limit
  - $35.9 \text{ fb}^{-1}$ (13 TeV)

- **$|V_{eN}|^2$** vs $m_N$ (GeV)
  - CLs Observed
  - CLs Expected

- **$|V_{\mu N}|^2$** vs $m_N$ (GeV)
  - CLs Observed
  - CLs Expected

Dermot Moran (CIEMAT)

March 20, 2018
ATLAS and CMS have extensive search programs using boosted objects.

- Sensitivity to a large range of BSM physics
- Latest results with 2016 and 2015 data show no surprises
- 2017 analyses also well underway, watch this space!