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Search for heavy resonances decaying to top quarks

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Why top quarks?

- Top quarks are heavy $\rightarrow$ Very large Yukawa coupling
- Many scenarios for beyond the Standard Model physics predict enhanced couplings to third generation quarks, non-SUSY examples:
  - heavy mediators ($H$, $A$, $Z'$, $W'$, $g_{KK}$, $G_{KK}$)
  - top partners (Vector-like quarks, see Romain Kukla’s talk)
"Jet substructure as a new Higgs search channel at the LHC"

Intermission:
Top decays

At rest/resolved:

R = 0.4

“Boost”

R = 1.0

large-R jet
Jet substructure as a new Higgs search channel at the LHC


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Intermission:

Top decays

- "QCD-jet"
- "top-jet"

ATLAS Simulation
Pythia $Z' \to t\bar{t}$, $t \to Wb$

$\Delta R \simeq 2m/p_T$

JHEP09 (2013) 076

$R = 1.0$

large-R jet
Search for $t\bar{t}$ resonances in the lepton + jets channel @ 13 TeV

1 large-R jet (trimmed anti-$k_t$, $R=1.0$, $p_T>300$ GeV), top-tagged

1 $b$-tagged Jet (anti-$k_t$ track Jet, $R=0.2$)

missing transverse momentum

1 electron/muon

$W^+ + \nu_e + e^+$

$W^- + \bar{t} + \bar{b} + q + \bar{q}$
Search for \(t\bar{t}\) resonances in the lepton + jets channel @ 13 TeV

1 large-R jet
(trimmed anti-k\(_t\), R=1.0, p_T>300 GeV), top-tagged

missing transverse momentum

\(\nu_e e^+\)

ATLAS Preliminary
\(\sqrt{s} = 13\) TeV, 3.2 fb\(^{-1}\)

Data / 20 GeV

Events / 20 GeV

ATLAS

electron

Data / Bkg.
Search for tt resonances in the lepton + jets channel @ 13 TeV

1 large-R jet (trimmed anti-kt, R=1.0, pT>300 GeV), top-tagged

Large-R jet mass [GeV]

Data / Bkg.

Events / 10 GeV

νe

e+

缺失的电荷

ATLAS Preliminary

νe

e+

缺失的电荷

ATLAS Preliminary
Top pair mass

Signal (simulation)
$Z' \rightarrow t\bar{t}$

data+background MC

ATLAS-CONF-2016-014
Systematics and limits for $Z' \rightarrow t\bar{t}$

- biggest uncertainties due to large R jet scale uncertainties
- $0.7 < m_{Z'} < 2.0$ TeV excluded at 95% C.L.
H/A→tt @8 TeV

- 2HDM Type II: heavy pseudo/scalar A/H → tt
- Interferes with SM tt production (same initial and final states)
- Generate Signal+Interference events using MadGraph5_aMC@NLO
- Reinterpretation of Run 1 search (JHEP 08 (2015) 148)
H/A—>tt Results

- Resolved selection:
  - 1 electron/muon
  - at least 4 jets
  - at least 1 b-jet
  - $\chi^2$ to reconstruct top candidates

No sign of scalar/pseudo scalar

—> set limits in 3 scenarios:

$\sqrt{s} = 8$ TeV, 20.3 fb$^{-1}$, all limits at 95% CL

- only $m_A$
- only $m_H$
- $m_A = m_H$
W’ to $t\bar{b}$ resonances @ 8 TeV

- Leptophobic $W'$ to $t\bar{b}$
- Boosted all hadronic with substructure based top tagging
- $l+jets$

Exclusion:

$m_{W'L} < 1.68$ TeV
$m_{W'R} < 1.76$ TeV
$m_{W'L} < 1.7$ TeV
$m_{W'R} < 1.92$ TeV
Intermission: Shower deconstruction

- Make subjets from large R jets
- Assume each subjet comes from a certain particle
- Calculate probability of particle-subjet association using QCD principles
- Repeat for all possibilities and with signal* and background hypothesis
- Single analytic function:

\[ \chi_{SD}(\{p_i^k\}) = \frac{\sum_{\text{perm}} P(\{p_i^k\} | \text{top-quark jet})}{\sum_{\text{perm}} P(\{p_i^k\} | \text{gluon/light-quark jet})} \]

* Signal can be any hadronic decay (top, W, H, …)
**SD Update for high $p_T$**

- So far used SD with C/A $R=0.2$ subjets, good proxies for partons with $\Delta R>0.2$
- SD needs $n_{\text{subjet}} \geq 3$ to work (i.e. for three top decay partons)

- **New:** At large $p_T$ use exclusively $k_T^*$ clustered jets
- Provides more $n_{\text{subjet}} \geq 3$ large input jets to SD —> Larger efficiency at high $p_T$.

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W’ to $t\bar{b}$ @13 TeV

- Trigger: 1 small-R jet, $p_T > 420$ GeV
- Large-R jets: trimmed anti-$k_t$ R=1.0 jet, $p_T > 420$ GeV
- Pick large-R jet with highest $m_{\text{leading small-R}} + 0.15 m_{\text{large-R}}$
- Top tag via *Shower Deconstruction*
  - eff = 50% $\rightarrow$ rejection = 80
  - eff = 80% $\rightarrow$ rejection = 25
  - Test SD in lep+jet tt events
- b-tagging: 77% eff., MVA-based
  - b-jet candidate = highest $p_T$ small-R jet, $\Delta R > 2.0$ from large-R
- Split in 1 and 0 “b-tag-in”, i.e. within/ not within $\Delta R = 1.0$ of top jet
QCD Estimate

- Estimate QCD multijet (and a few V+jet) events from $t\bar{t}$ subtracted data in control regions:

$$N_A^{bkg} = R_A^{corr} \cdot \frac{(N_C^{data} - N_C^{t\bar{t}}) \cdot (N_D^{data} - N_D^{t\bar{t}})}{N_F^{data} - N_F^{t\bar{t}}}$$

- Correlation of top- and b-tagging from PYTHIA, uncertainties from 4 alternative multijet samples
Uncertainties and fit to data

- Profile LLH fit to data
- Systematic uncertainties are constraint
- Main uncertainties: QCD-estimate and b-tagging, statistically dominated for $m_{tb} > 2$ TeV

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

ATLAS-CONF-2017-082
Limits on $W'\rightarrow t\bar{b}$

**Reminders:**
- Best Run 1 $W'\rightarrow tb$ limit was just below 2 TeV!
- $W'\rightarrow e/\mu\nu$ @ 5 TeV, but not sensitive to $W'_R$


Observed 95% CL limits, exclude:
- $m_{W'_L} < 2.95$ TeV,
- $m_{W'_R} < 2.98$ TeV

NEW!

ATLAS-CONF-2017-082
Conclusions

• No sign of new heavy resonances decaying to top quarks
• Leptophobic Z’ excluded up to 2 TeV with a subset of the Run2 data
• Inclusion of interference effects in search for scalar
• Significant improvement of limit on W’ mass compared to Run 1
• More data and improved analysis strategies will push the limits further and will hopefully reveal signs of new physics!