SEARCH FOR PHYSICS BEYOND THE STANDARD MODEL WITH TOP QUARKS AT ATLAS

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Motivation:

- Large top ($t$) mass, close to scale of electroweak (EW) symmetry breaking
- LHC is a top factory. Top pair ($t\bar{t}$) production cross section: $\sim 177$ pb
- Experimental excess on $t\bar{t}$ $A_{FB}$ measurement at the Tevatron

Outline:

- Luminosity at ATLAS
- Top pairs and top quark decays
- Search for $t\bar{t}$ resonances in the di-lepton channel
- Search for $t\bar{t}$ resonances in the lepton plus jets channel
- Search for new physics in $t\bar{t}$ events with large missing transverse momentum ($E_T$)
- Search for same-sign top quark ($tt$) production
Luminosity at ATLAS

- The instantaneous luminosity has been increasing significantly
- The integrated luminosity recorded at ATLAS has reached $5.3 \text{ fb}^{-1}$ ($5.6 \text{ fb}^{-1}$ delivered) in 2011
- Analyses shown today include integrated luminosities from 1 to 2 fb$^{-1}$
Top pairs and top quark decays

- Top quark may decay leptonically or hadronically

- Top pairs ($t\bar{t}$) signatures:
  - di-lepton: low branching ratio ($Br$), low background
  - lepton+jets: compromise between $Br$ and background
  - all jets: large $Br$ and large multi-jet background

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Search for $t\bar{t}$ resonances in the di-lepton channel

- Preliminary result, August 2011 [ATLAS-CONF-2011-123]
- $\mathcal{L} = 1.04$ fb$^{-1}$
- $t\bar{t}$ decay: di-leptonic ($t \rightarrow Wb \rightarrow \ell\nu b$)
- 3 channels: $ee$, $e\mu$, $\mu\mu$
- Main observable: $H_T + \not{E}_T$ with $H_T = \sum_\ell p_T^\ell + \sum_{jets} p_T^{jet}$
- Event selection:
  - $\geq 2$ jets and $= 2$ OS leptons
  - $|m_Z - m_{\ell\ell}| > 10$ GeV
  - $\not{E}_T > 40$ GeV
  - $H_T > 130$ GeV in $e\mu$ channel
- Production of top pairs via an unknown mediator $X$ at the LHC (e.g.: $Z'$, $g_{KK}$):
- Main backgrounds:
  - $t\bar{t}$, single top (MC@NLO)
  - $Z/\gamma^* \rightarrow \ell\ell$ (ALPGEN)
    - $\ell \in \{e, \mu\}$ for same-flavor channel
    - $\ell = \tau$ for $e\mu$ channel
    - Normalization to Data in control region with $Z$ in its mass window
Search for $t\bar{t}$ resonances in the **di-lepton** channel

- **Main systematics:**
  - Signal ($m_{g_{KK}} = 1$ TeV): lepton efficiency (4.7%), jet calibration (up to 6.8%), ISR/FSR (4.5%)
  - SM background: generator (4.8%), jet calibration (7.4%), lepton efficiency (4.5%)

- **Limits:**
  - Derived from binned $H_T + \not{E_T}$ variable
  - Coupling $\frac{g_{qgKK}}{g_s}$ from 0.2 to 0.35
  - Observed lower bounds on $m_{g_{KK}}$ from 0.8 to 1.02 TeV
Search for $t\bar{t}$ resonances in the lepton plus jets channel

- Preliminary result, March 2012 [ATLAS-CONF-2012-029]
- $L = 2.05$ fb$^{-1}$
- $t\bar{t}$ decay: semi-leptonic
- 2 channels: $\ell \in \{e, \mu\}$
- Event selection:
  - $e$ channel: $E_T > 35$ GeV and $m_T > 25$ GeV
  - $\mu$ channel: $E_T > 20$ GeV and $E_T + m_T > 60$ GeV
  - if any jet with $m_j > 60$ GeV: $n_{jets} \geq 3$
  - if no jet with $m_j > 60$ GeV: $n_{jets} \geq 4$
  - Leading jet fulfills: $p_T > 60$ GeV
  - Require at least one $b$-tagged jet

- Main backgrounds:
  - $t\bar{t}$, single top (MC@NLO)
  - $W$+jets (ALPGEN and normalized to Data)
- QCD multi-jet (fake lepton) estimated using data-driven template

![Graph showing leading jet mass vs events]
Search for $t\bar{t}$ resonances in the lepton plus jets channel

- $t\bar{t}$ mass reconstruction:
  - $m_{t\bar{t}}$ derived from lepton, $\not{E}_T$, and leading 3 or 4 jets
  - $\nu p_z$ determined using $W$ mass constraint
  - If no jet with $m_j > 60\text{ GeV}$: 3 or 4 jets considered are close to lepton or another jet (iterative procedure)
  - If jet with $m_j > 60\text{ GeV}$:
    - hadronic $t$ formed by high-mass jet + closest jet
    - leptonic $t$ formed by $\ell +$ closest jet
Search for $t\bar{t}$ resonances in the lepton plus jets channel

- Main systematics (none more than 15% of total):
  - Normalization: 1.5% (lepton efficiency) to 50% (QCD)
  - Signal/background shapes: 0.9%/0.8% (ISR/FSR) to 18.9%/16.5% ($b$-tagging)

- Scenarios for production of $t\bar{t}$:
  - narrow resonances: via leptophobic $Z'$
  - wide resonances: via Kaluza-Klein gluon $g_{KK}$ (Randall-Sundrum models)

- Limits:
  - Derived from binned $m_{t\bar{t}}$ variable
    - $500 < \frac{m_{Z'}}{\text{GeV}} < 860$
    - $500 < \frac{m_{g_{KK}}}{\text{GeV}} < 1025$
Search for new phenomena in $t\bar{t}$ events with large $E_T$

- Published [PRL 108 (2012) 041805]
- $\mathcal{L} = 1.04$ fb$^{-1}$
- Scenario: pair production of $4^{th}$ generation quark ($T$) with: $T \rightarrow tA_0$ ($A_0$ is stable, neutral, weakly-interacting)
- More 4th generation quark scenarios: DIS 2012 contribution Id 200
- $t\bar{t}$ decay: semi-leptonic
- Event selection:
  - single lepton trigger
  - $n_{jets} \geq 4$
  - $E_T > 100$ GeV and $m_T(\ell, E_T) > 150$ GeV
  - Veto events with additional lepton or isolated track (reduce single prong $\tau_h$ decay in $t\bar{t}$ events)
- Main backgrounds:
  - di-leptonic $t\bar{t}$ decay ($\ell$ missed or $\ell = \tau_h$)
  - single-lepton background: $W +$jets and semi-leptonic $t\bar{t}$ decay (normalization and shape data-driven)
Search for new phenomena in $t\bar{t}$ events with large $E_T$

- **Main systematics:**
  - Jet calibration in simulation: 11%
  - Second lepton veto efficiency in di-lepton $t\bar{t}$: 10%
  - Shape correction in data-driven single-lepton background: 15%
  - Scale uncertainty and PDF in signal: 10 to 15%

- **Limits:**
  - Assume $\text{Br}(T\bar{T} \rightarrow t\bar{t}A_0A_0) = 1$
  - Exclusions:
    - $m_T < 420$ GeV for $m_{A_0} < 10$ GeV
    - $330 < \frac{m_T}{\text{GeV}} < 390$ for $m_{A_0} < 140$ GeV
  - $\sigma_{T\bar{T}}$ for spin-$\frac{1}{2}$ $T\bar{T}$ models below sensitivity (e.g.: $\tilde{t}/\chi_0$, $LQ_3/\nu_\tau$)
Search for same-sign top quark production

- Submitted to JHEP, February 2012 [arXiv:1202.5520]
- \( \mathcal{L} = 1.04 \text{ fb}^{-1} \)
- 2 leptonic \( t \) decays \( \rightarrow \) same-sign di-lepton
- Analysis of \( ee \) and \( \mu\mu \) channels
- Event selection:
  - 2 same-sign leptons with \( m_{\ell\ell} > 15 \text{ GeV} \) and \( |m_{\ell\ell} - m_Z| > 10 \text{ GeV} \)
  - \( \geq 2 \) jets
  - \( \vec{E}_T > 40 \text{ GeV} \)
  - if \( tt \) via high-mass \( Z' \):
    \( H_T > 350 \text{ GeV} \)
  - if \( tt \) via low-mass \( Z' \):
    \( H_T > 150 \text{ GeV} \) and \( m_{\ell\ell} > 100 \text{ GeV} \)

- Background:
  - fake \( \ell \): hadronic decays, photon conversion (data-driven)
  - charge mis-Id (data-driven)
  - \( W/Z \) di-boson (simulation)
Search for same-sign top quark production

- Possible scenario via vector boson (Z') coupling to u and t (\(\bar{u}u \rightarrow \bar{t}t\) suppressed at high Bjorken-x)

  \(tt\) via Z'-mediated FCNC could explain Tevatron \(t\bar{t}\) \(A_{FB}\) results (excess over SM)

- Main systematics (Signal/Background):
  - Jet calibration: 2.3%/7.1%
  - Electron efficiency: 4.2%/2.0%
  - Muon efficiency: 5.8%/3.0%
  - LAr calorimeter readout: 3.0%/2.0%

- Exclusions:
  - Heavy Z' mediator: \(\sigma < 1.7\) pb
  - Light mediator: \(\sigma < 1.4\) to 2.0 pb
Conclusion

- No evidence of new physics with top quark at ATLAS, but significant improvement of limits
- Results shown based on 1 to 2 fb$^{-1}$ and $\sqrt{s} = 7$ TeV
  → More results to come with complete 2011 dataset (5 fb$^{-1}$)
  → Prospects for 2012 Data: $\sqrt{s} = 8$ TeV

- For further details, see:
  - ATLAS Exotics results:
    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
  - ATLAS Top results:
    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults