

Measurements of tt+X using the ATLAS detector

Alexander Khanov Oklahoma State University for the ATLAS Collaboration DIS16, DESY Hamburg, Germany 4/13/16

Top quark

- Top: heaviest quark, mass at the EW scale
 - top production and decays provide important tests of QCD in nonperturbative mode
 - deviation from SM prediction = indication of new physics
- Top quarks are produced in abundance at the LHC
 - a lot of opportunities to study their properties



Summary of reported results

- tt+W/Z: 8 TeV, 13 TeV
- tt+jets:13 TeV
- tt+HF: 8 TeV
- tt+γ: 7 TeV

tt+W/Z production (8 TeV, 20.3/fb)

- First direct measurement of ttZ coupling
- Affected by various BSM scenarios (strongly coupled Higgs sector, technicolor)



- Analysis done in four channels:
 - opposite sign dilepton ($p_T > 15$ GeV): ≥ 3 jets, ≥ 1 b-tags
 - 2I-noZ: Etmiss>40 GeV, main background: tt
 - 2I-Z: $|m_{\parallel}-m_{Z}|$ <10 GeV, main background Z+jets
 - use NN to separate signal from background in jet multiplicity bins
 - same sign dilepton (p_T>25 GeV)
 - Etmiss>40 GeV, H_T >240 GeV, ≥ 2 b-tags
 - targets ttW, dominant backgrounds are instrumental (fakes, charge flips)
 - trilepton (p_T >15 GeV)
 - 3I-Z-1b4j, 3I-Z-2b3j, 3I-Z-2b4j: ttZ; 3I-noZ-2b: ttW
 - dominant backgrounds: dibosons, instrumental
 - tetralepton (p_T>7 GeV): 4l&3l taken as 3l, 4l&2l negligible
 - dominant background: ZZ

A.Khanov, DIS16

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tt+W/Z production: results

Measured cross-sections:

$$\sigma_{t\bar{t}W} = 369^{+86}_{-79}$$
(stat.) ± 44 (syst)fb = 369^{+100}_{-91} fb

$$\sigma_{t\bar{t}Z} = 176^{+52}_{-48}$$
(stat.) ± 24 (syst.) fb $= 176^{+58}_{-52}$ fb

600

400

ttZ cross section [fb]

ATLAS

500 ⊣ s = 8 TeV, 20.3 fb

ATLAS Best Fit

ATLAS 68% CL

ATLAS 95% CL

NLO prediction*

ttZ Theory uncertainty

ttW Theory uncertainty

600

- Simultaneous fit: 5.0 σ for ttW, 4.2 σ for ttZ
- All measurements consistent ulletwith QCD NLO predictions



tt+W/Z production (13 TeV, 3.2/fb)

- Analyzed channels: same sign dilepton (μμ highest sensitivity since electrons are more susceptible to instrumental backgrounds), trilepton, tetralepton
- Measured cross-sections:

 $\sigma_{t\bar{t}W} = 0.92 \pm 0.30(\text{stat.}) \pm 0.11(\text{syst.})\text{pb}$ $\sigma_{t\bar{t}Z} = 1.38 \pm 0.70(\text{stat.}) \pm 0.33(\text{syst.})\text{pb}$



perform binned maxlikelihood fit to the number of events, systematics are included through profiling

all measurements consistent with NLO QCD predictions

ATLAS-CONF-2016-003

tt+jets production (13 TeV, 3.2/fb)

- Sensitive to higher order perturbative QCD effects
- Uncertainty in tt+jets production is a significant source of uncertainty in precision measurements, e.g. top mass
- Dominant background in various Higgs studies and NP searches
 - Previous ATLAS tt+jets measurements:
 - 7 TeV: JHEP 1501 (2015) 020, arXiv:1407.0891
 - 8 TeV: arXiv:1511.04716, subm. to EPJC
 - Done in tt \rightarrow I+jets
 - can't accurately define additional jets, looking at overall jet multiplicity

ATLAS-CONF-2015-065

tt+jets production (cont'd)

- Selection: two opposite sign leptons with p_T>25 GeV + two b-tagged jets
- clean (90%), main backgrounds: Wt, Z+jets (ee/μμ), fakes (ee/eμ)
- events are categorized in terms of the number of additional jets (excluding the two tagged jets) above p_T threshold (25, 40, 60, 80 GeV)



tt+jets production: results

- The results are unfolded to the particle jet level $(M^{-1})^{\text{part},i}_{\text{reco},j}$
- Iterative Bayesian unfolding: $N_{cor}^i = \frac{1}{2}$

little difference for low p_{τ} cuts (25, 40 GeV)

- Results are compared to Powheg + (Pythia6 / Pythia8 / Herwig++) and aMC@NLO/Herwig++
 - all consistent with data

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matrix

$$\cdot g^{j} \cdot (N_{\text{reco}}^{j,\text{data}} - N_{\text{bg}}^{j})$$

correction for events that satisfy *reco* but fail *part*

Pythia6 tends to underestimate data at high multiplicity ٠



measurement uncertainty: tt+1j: 9—10% tt+2j: 13—14% systematics dominated (jets, MC modeling)

tt+HF production (8 TeV, 20.3/fb)

- Theoretical calculations of tt+HF have significant uncertainties, experimental measurement is desirable
- tt+bb is main background to ttH, H→bb and various BSM searches, e.g. t(b)H+, H+→tb
- Methods: cut-and-count (ttbb), tag weight (MV1c) template fit (ttbb, ttb→l+jets, ttb→eµ)
- Three measurements referring to different fiducial definitions

| ttbb | | ttb→l+jets | | ttb→eμ | | | |
|------|------------|------------|---------------|--------|-------------|---------------------------------|--|
| | | | | | | Eur. Phys. J. C | |
| ttbb | nj≥4, nb≥4 | ttb | ni≥5. nb≥3 | ttb | ni≥3. nb≥3 | (2016) 76:11 | |
| tthX | nh-3 | | | | ···j; ···· | | |
| LLDA | 10-5 | ttc | nj≥5 <i>,</i> | ttc | nj≥3, | | |
| ttcX | nb=2,nc≥1 | | nb=2,nc≥1 | | nb≤2,nc≥1 | potentially consitive to the | |
| ttlX | other | ttl | other | ttl | other | sensitive to tic | |
| | | | | domina | ted by W→cs | | |

tt+HF production (cont'd)

- ttbb, ttb→eµ: cleanest (tt→eµ signal fraction ~96%), statistical uncertainty ~ systematic uncertainty
 - dominant background: single top
- ttb→l+jets: systematics limited
 - dominant backgrounds: V+jets, single top



tt+HF production: results

 Measured: fiducial cross-sections for ≥1 and ≥2 additional b-jets, R_{ttbb}=σ(ttbb)/σ(ttjj)
 ttb production higher

| Analysis | Measured | Predicted | |
|---------------------------------|---|--------------------|--|
| | Cross-section [fb] | Cross-section [fb] | |
| σ_{ttb} lepton-plus-jets | 950 ± 70 (stat.) $^{+240}_{-190}$ (syst.) | 720 | |
| $\sigma_{ttbe\mu}$ | 50 ± 10 (stat.) $^{+15}_{-10}$ (syst.) | 38 | |
| σ_{ttbb} cut-based | 19.3 ± 3.5 (stat.) ± 5.7 (syst.) | 12.3 | |
| $\sigma_{ttbb fit-based}$ | 13.5 ± 3.3 (stat.) ± 3.6 (syst.) | 12.3 | |
| <i>R</i> _{ttbb} | 1.30 ± 0.33 (stat.) ± 0.28 (syst.) % | 1.27 % | |



ttb production higher than Powheg+Pythia6 prediction by ~30%

these numbers include contributions from ttH, ttV; MC subtracted results are also available



tt+γ production (7 TeV, 4.59/fb)

- Direct measurement of ttγ coupling
- Affected by various BSM models, e.g. excited top production $t^* \rightarrow t\gamma$
- this analysis: tt→l+jets decay channel
- selection: $1I + \ge 4$ jets, ≥ 1 b-tagged jets
 - μ+jets: p_T>20 GeV, ETmiss>20 GeV, Etmiss+MTW>60 GeV
 - e+jets: p_T>25 GeV, ETmiss>30 GeV
- photons: p_T>20 GeV

sample composition:

| Contribution | Electron chan. | Muon chan. | Total |
|------------------|----------------|--------------|--------------|
| Signal | 52 ± 14 | 100 ± 28 | 152 ± 31 |
| Hadrons | 38 ± 26 | 55 ± 38 | 93 ± 46 |
| Prompt photons | 41 ± 5 | 65 ± 9 | 106 ± 10 |
| Total background | 79 ± 26 | 120 ± 39 | 199 ± 47 |
| Total | 131 ± 30 | 220 ± 48 | 351 ± 59 |
| Data candidates | 140 | 222 | 362 |

• signal extraction: template of trackisolation distributions



- tty is observed with 5.3σ significance
- measured cross-section
 ×BR in fiducial volume is in agreement with theory

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Conclusions

- Huge available tt statistics provides possibility to study the tt+X production
- For the first time we are able to directly measure the top couplings and differential cross-sections
- All the presented measurements are compatible with the SM predictions
- Obtained results help to test theory predictions, provide solid basis for new physics searches

13 TeV tt+1 jet event display

• muon $p_T = 140$ GeV, electron $p_T = 170$ GeV, three jets, two of them b-tagged

