Top quark associated production at CMS

Pieter David
on behalf of the CMS collaboration

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Top quark associated production

• Top quark decay: dominated by $t \rightarrow Wb$ ($V_{tb}$ coupling)
• Associated production gives access to top-boson and to BSM couplings

Operators and processes

\[ O^{(3)}_{Q} = i \frac{1}{2} y_t^2 \left( \tilde{Q} \gamma^{\mu} \gamma^{\nu-} Q \right) \]
\[ O^{(1)}_{Q} = i \frac{1}{2} y_t^2 \left( \tilde{Q} \gamma^{\mu} \tilde{Q} \right) \]
\[ O_{\varphi t} = i \frac{1}{2} y_t^2 \left( \tilde{Q} \gamma^{\mu} \varphi \right) \]
\[ O_{\varphi b} = i \frac{1}{2} y_t^2 \left( \tilde{Q} \gamma^{\mu} \varphi \right) \]
\[ O_{tW} = y_t g_w \left( Q_{\sigma^{\mu\nu}} t \right) \tilde{\varphi} W_{\mu\nu} \]
\[ O_{bW} = y_t g_w \left( Q_{\sigma^{\mu\nu}} t b \right) \varphi W_{\mu\nu} \]
\[ O_{tB} = y_t g_Y \left( Q_{\sigma^{\mu\nu}} t \right) \tilde{\varphi} B_{\mu\nu} \]
\[ O_{gG} = y_t g \left( Q_{\sigma^{\mu\nu}} T_A t \right) \tilde{\varphi} G^A_{\mu\nu} \]
\[ O_{t\varphi} = (\varphi^\dagger \varphi) \left( \tilde{Q} t \right) \]
\[ O_{\varphi t b} = i (\varphi^\dagger D_\mu \varphi) \left( \tilde{t} \gamma^\mu b \right) \]

Pieter David (UCLouvain-CP3)
Top quark associated production at CMS

January 2018

Production Cross Section, $\sigma$ [pb]

CMS Preliminary

- 7 TeV CMS measurement ($L \leq 5.0 \, fb^{-1}$)
- 8 TeV CMS measurement ($L \leq 19.6 \, fb^{-1}$)
- 13 TeV CMS measurement ($L \leq 35.9 \, fb^{-1}$)
- Theory prediction
- CMS 95%CL limits at 7, 8 and 13 TeV

All results at: http://cern.ch/go/pNj7

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Vector boson production

Higgs

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π jet(s)
π jet(s)

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Vector boson production

Higgs

single top

ttH

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pp → ℓ⁺jets participles level 

- $\ell + \text{jets}$, background-subtracted (from non-\(b\)-tagged data, except for single top) and unfolded to particle level

- Differential cross-section measurements as a function of top quark, top decay product, and additional jet kinematic variables

- Overall reasonable agreement with POWHEG+PYTHIA8, larger differences with SHERPA with the Catani-Seymour parton shower

- Useful input for further tuning of parton shower models

see also the talks by Juan and Javier for more details about this analysis

35.8 fb⁻¹ (13 TeV)
pp → tt + jets (tt → ℓ + jets) at $\sqrt{s} = 13$ TeV

- $\ell +$ jets, background-subtracted (from non-b-tagged data, except for single top) and unfolded to particle level
- Differential cross-section measurements as a function of top quark, top decay product, and additional jet kinematic variables
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ΔR between the leading additional jet and the closest top quark

see also the talks by Juan and Javier for more details about this analysis
$pp \rightarrow \bar{t}t + \text{jets}$ ($\bar{t}t \rightarrow \ell + \text{jets}$) at $\sqrt{s} = 13$ TeV

- $\ell + \text{jets}$, background-subtracted (from non-b-tagged data, except for single top) and unfolded to particle level
- Differential cross-section measurements as a function of top quark, top decay product, and additional jet kinematic variables
- Overall reasonable agreement with POWHEG+PYTHIA8, larger differences with SHERPA with the Catani-Seymour parton shower
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$\Delta R$ between the leading additional jet and the closest top quark

See also the talks by Juan and Javier for more details about this analysis
pp → t\bar{t} + b-jets (t\bar{t} → dilepton) at \sqrt{s} = 13 \text{ TeV}

- interesting test of QCD calculations, and also important as a background to other top associated processes (especially t\bar{t}H with H → bb)

- Event selection:
t\bar{t} → dilepton with at least 4 jets, at least 2 b-tagged

- b-tagging discriminant distribution in simulation corrected from data

- dominant uncertainty:
b-jet (mis-)tagging calibration
$pp \to \bar{t}t + W/Z$ cross-sections at $\sqrt{s} = 13$ TeV

- (same-sign) dilepton, three-lepton and four-lepton categories
- Kinematic BDT ($2\ell$) and (b-)jet multiplicity categories
- Data-driven non-prompt and charge-misidentified lepton background, WZ from control region
\[ \sigma(pp \rightarrow \bar{t}tW) = 0.77^{+0.12}_{-0.11} \text{ (stat.)}^{+0.13}_{-0.12} \text{ (sys.) \ pb} \]
\[ \sigma(pp \rightarrow \bar{t}tZ) = 0.99^{+0.09}_{-0.08} \text{ (stat.)}^{+0.12}_{-0.10} \text{ (sys.) \ pb} \]
pp → t¯t + W/Z cross-sections: EFT interpretation

- LO t¯tW, t¯tZ and t¯tH cross-sections parameterized as a function of Wilson coefficients (in the HEL basis)
- Only considering operators that do not have a large impact on t¯t, VV and H cross-sections (and rare backgrounds)
- One coefficient fit at a time

more EFT fit plots can be found on the results web page

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Wilson coefficient | Best fit [TeV^−2] | 68% CL [TeV^−2] | 95% CL [TeV^−2]
---|---|---|---
| ¯c_{uW}/Λ² | 1.7 | [−2.4, −0.5] and [0.4, 2.4] | [−2.9, 2.9] |
| | | | [0, 28.5] |
| | | | [0, 0.9] |
| | | | [−0.7, 1.0] |
| | | | [−1.0, −0.9] and [−0.3, 0.4] |
| | | | [0, 2.7] |
| | | | [−11.1, −6.5] and [−1.6, 3.0] |
| | | | [−1.1, 0.8] |
| | | | [−11.1, −6.5] and [−1.6, 3.0] |
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| | | | [−1.1, 0.8] |

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*Pieter David (UCLouvain-CP3) Top quark associated production at CMS*
• Enhanced in many BSM theories, also sensitive to the top quark Yukawa coupling $y_t$

• Multilepton ($\ell^{\pm}\ell'^{\pm}$, 3$\ell$, 4$\ell$) final states

• 8 signal regions and $t\bar{t}W$, $t\bar{t}Z$ control regions based on the number of leptons, jets and $b$-tagged jets (and a $Z \rightarrow \ell^+\ell^-$ veto)

• Backgrounds from nonprompt and charge mis-identified leptons estimated using a “fake rate” method

• Improved description of $t\bar{t}W + \text{jets}$ and $t\bar{t}Z + \text{jets}$ backgrounds using corrections derived from $t\bar{t}(\text{dilepton}) + \text{jets}$ and $t\bar{t}b\bar{b}/t\bar{t}jj$ measurements
Search for Standard Model $pp \rightarrow t\bar{t}t\bar{t}$ production

$\sigma(pp \rightarrow t\bar{t}t\bar{t}) = 16.9^{+13.8}_{-11.4}$ fb (NLO prediction: $9.2^{+2.9}_{-2.4}$ fb [MG5_AMC@NLO])

Signal significance: $1.6\sigma$ (1.0σ expected)

$\sigma(pp \rightarrow t\bar{t}t\bar{t}) < 41.7$ fb at 95% CL (background-only expected: $20.8^{+11.2}_{-6.9}$ fb)

$|\gamma_t/\gamma_t^{SM}| < 2.1$ with $\sigma_{SM} = 12.2^{+5.0}_{-4.4}$ fb

Search for Standard Model pp → tttt production

\[ \sigma(pp \rightarrow tttt) = 16.9^{+13.8}_{-11.4} \text{ fb} \] (NLO prediction: 9.2^{+2.9}_{-2.4} \text{ fb} [MG5_AMC@NLO])

Signal significance: 1.6\( \sigma \) (1.0\( \sigma \) expected)

\[ \sigma(pp \rightarrow tttt) < 41.7 \text{ fb} \] at 95% CL (background-only expected: 20.8^{+11.2}_{-6.9} \text{ fb})

\[ |y_t/y_t^{SM}| < 2.1 \] with \( \sigma_{SM} = 12.2^{+5.0}_{-4.4} \text{ fb} \)

Conclusions

- Top quark associated production provides an interesting opportunity to search for physics beyond the standard model by measuring SM couplings of the top quark and dimension-6 Wilson coefficients.

- The measurements of these processes are challenging, but many are now feasible with an interesting precision, thanks to the large LHC run-2 data samples collected at $\sqrt{s} = 13$ TeV.

- Presented measurements of $t\bar{t}$ production in association with jets, b-jets, W and Z bosons and another $t\bar{t}$ pair. Most are based on only 36 fb$^{-1}$ (2016 data), and limited by statistics or systematic effects that can be further constrained with more data, so they will improve with the 2017 and 2018 data samples.
Additional material
pp → tt + γ cross-section at $\sqrt{s} = 8$ TeV

- Fiducial region: photon $E_T > 25$ GeV, $|\eta| < 1.44$
- tt+jets and V+γ backgrounds determined from fits to M3 (hadronic top mass) and photon isolation (with templates from data: random cone (PU) for isolated, photon $\eta$ spread sideband for photons from jets)
- $e \rightarrow \gamma$ mis-ID rate corrected with $Z \rightarrow e^+e^-$
- $\sigma_{tt+\gamma}^{\text{fid}} / \sigma_{tt} = 5.2 \pm 1.1 \times 10^{-4} (\text{stat+syst})$
- $\sigma_{tt+\gamma}^{\text{fid}} = 127 \pm 27 (\text{stat+syst})$ fb
- photon $E_T$ and $\eta$ distributions in good agreement with simulation
pp → t¯t + γ cross-section at √s = 8 TeV

- Fiducial region: photon E_T > 25 GeV, |η| < 1.44
- t¯t+jets and V+γ backgrounds determined from fits to M3 (hadronic top mass) and photon isolation (with templates from data: random cone (PU) for isolated, photon η spread sideband for photons from jets)
- e → γ mis-ID rate corrected with Z → e^+e^−
- \( \sigma_{t\bar{t} + γ}^{\text{fid}} / \sigma_{t\bar{t}} = 5.2 \pm 1.1 \times 10^{-4} (\text{stat+syst}) \)
- \( \sigma_{t\bar{t} + γ}^{\text{fid}} = 127 \pm 27 (\text{stat+syst}) \) fb
- photon E_T and η distributions in good agreement with simulation


References II


CMS collaboration, Measurement of the $t\bar{t}+\gamma$ production cross-section in pp collisions at $\sqrt{s} = 8$ TeV, CMS-PAS-TOP-14-008.