Search for four-top-quark production at $\sqrt{s} = 13$ TeV with the ATLAS detector at the LHC

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1. Introduction

- **LHC**: unique window to search for rare SM signatures
  - Extremely rare process: SM tttt cross-section $\approx 9.2$ fb (NLO in QCD), but powerful probe for many signatures of BSM physics;
  - Current limits: obs (exp) 95% CL of 4.5 (2.3) times SM expectation [1];
  - Can be studied in a variety of final states/channels, topology given by the decays of each W-boson ($t \rightarrow Wb$);

- 2 new searches [2, 3] for SM four-top-quark production using 36.1 fb$^{-1}$ of pp data at $\sqrt{s} = 13$ TeV collected by the ATLAS detector during 2015 and 2016;
  - Main focus here on the search using final states with the largest branching fraction (single-lepton and opposite-sign dilepton), and its combination with the search using same-sign (SS) dilepton and trilepton events.


- Final states with a single electron or muon, or dilepton events with 2 opposite-sign charged electrons or muons: small signal on top of large background dominated by production of $tt +$ extra jets;
  - Exploit the high jet ($b$), $b$-tagged jet ($b$) and reclustered large-$R$ jet ($\ell$) multiplicities, and the high scalar sum of the jet transverse momenta ($HT_{\text{vis}}$);
  - Events in each of the 2 channels are classified according to their event topology: highest sensitivity categories in single-lepton (OS dilepton) channel require at least 10 (8) jets, 4-$b$-tagged jets and 2 (1) reclustered jets.

3. Data-driven tt+jets estimation

- Inclusive tt MC simulation at NLO in QCD is not expected to model the very high jet/$b$-tagged regions well, relies on the description through parton showers with consequently large uncertainties;
  - Developed a data-driven method to estimate the dominant tt+jets background: assumes that the probability of $b$-tagging a jet in tt+jets event is essentially independent of the number of additional jets;
    - Tag-rate-function (TRF) formalism: for a given event with $N_j$ jets, the probability $P$ of containing exactly one $b$-tagged jet can be calculated as:
      $$ P(N_b=1) = \frac{N!}{N_b!(N-N_b)!} \cdot (1 - \varepsilon)^{N-N_b} \cdot \varepsilon^{N_b} $$
      where the $b$-tagging efficiencies ($\varepsilon$) are extracted as a function of jet $p_T$ and the minAR for the given jet w.r.t. to all other jets, multiplied by $N_j$;
  - Extract effective $b$-tagging efficiencies from low $N_j$ data (efficiency extraction regions), reweight (via tag-rate-function (TRF) formalism) the data in $N_b=2$ regions (source regions) and predict tt+jets in signal regions with same $N_j/N_b$, but larger Nb:

- All steps applied to MC simulated tt+jets events: derive a correction factor $C$ for each considered bin, reweighting the prediction by less than 20%;
  - A full set of systematic uncertainties is derived by repeating the procedure on MC simulated events with systematic variations applied.

4. Results and combination

- In the single lep. + OS dilepton channel, a simultaneous fit is performed to the $HT_{\text{vis}}$ distributions in 20 signal regions, data-driven estimation of tt+jets;
  - SS dilep. / trilep. cut-and-count analysis [3] in several regions, with data-driven estimations of non-prompt lepton and mis-identified charged leptons:
    - Results in both channels combined: excess of events over the SM background prediction observed with a significance of $2.8\sigma$ ($1.0\sigma$), Excess driven by the SS dilep. / trilep channel; compatibility between two channels quantified to be 31%;
    - Assuming no signal, obs. (exp.) 95% CL upper limit of 5.3 (2.1) times SM expectation.

References