Zooming in on top-quark production

August 8 2019

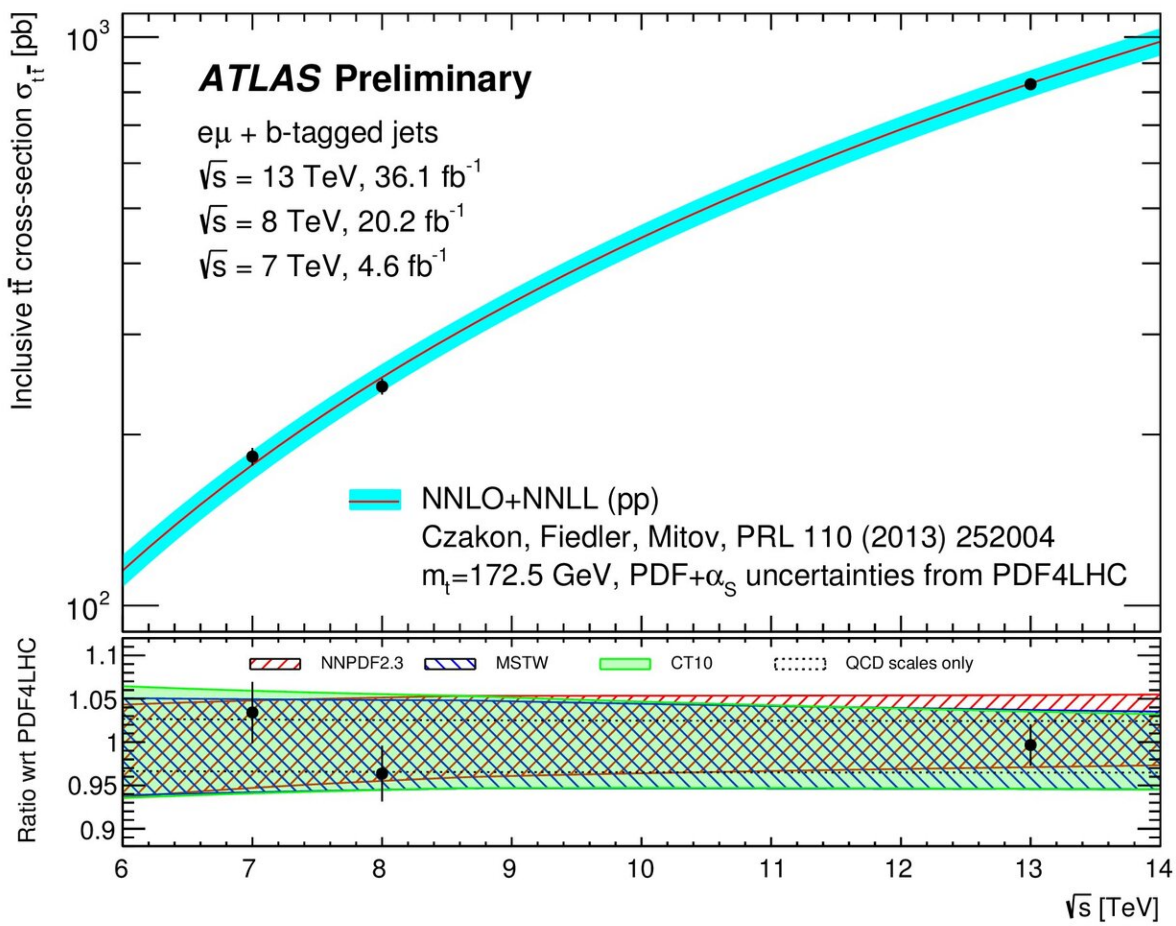

Figure 1: Top-quark-pair cross section measured by ATLAS at 13, 8 and 7 TeV using eμ events, compared to the theoretical prediction (cyan band) as a function of collision energy. The lower plot shows the ratio between measurements and predictions using various parton distribution functions. Credit: ATLAS Collaboration/CERN

As the heaviest known elementary particle, the top quark has a special place in the physics studied at the Large Hadron Collider (LHC) at CERN. Top quark-antiquark pairs are copiously produced in collisions recorded by the ATLAS detector, providing a rich testing ground for theoretical models of particle collisions at the highest accessible energies. Any deviations between measurements and predictions could point to shortcomings in the theory – or first hints of something completely new.

The ATLAS Collaboration has released a new precise measurement of the overall rate – or "cross section" – of top-quark-pair production at the LHC. The measurement uses events where one top quark decays to an electron (e), a neutrino and a b-quark, while the other decays to a muon (μ), a neutrino and a b-quark. This creates a striking signature in the detector, allowing physicists to collect a very clean sample of events with very little background. Despite accounting for only 2 percent of top-quark-pair decays, ATLAS physicists examined over 230,000 eμ events collected in 2015-2016 during Run 2 of the LHC at 13 TeV.

The new result gives a measurement of the top-quark-pair cross section of 826 ± 20 picobarns, i.e. an uncertainty of only 2.4 percent. This agrees perfectly well with state-of-the-art theoretical predictions, and joins previous precise ATLAS measurements that used 7 and 8 TeV data (Figure 1). This excellent precision is thanks, in large part, to the detector's superb reconstruction of the resulting leptons (electrons and muons).

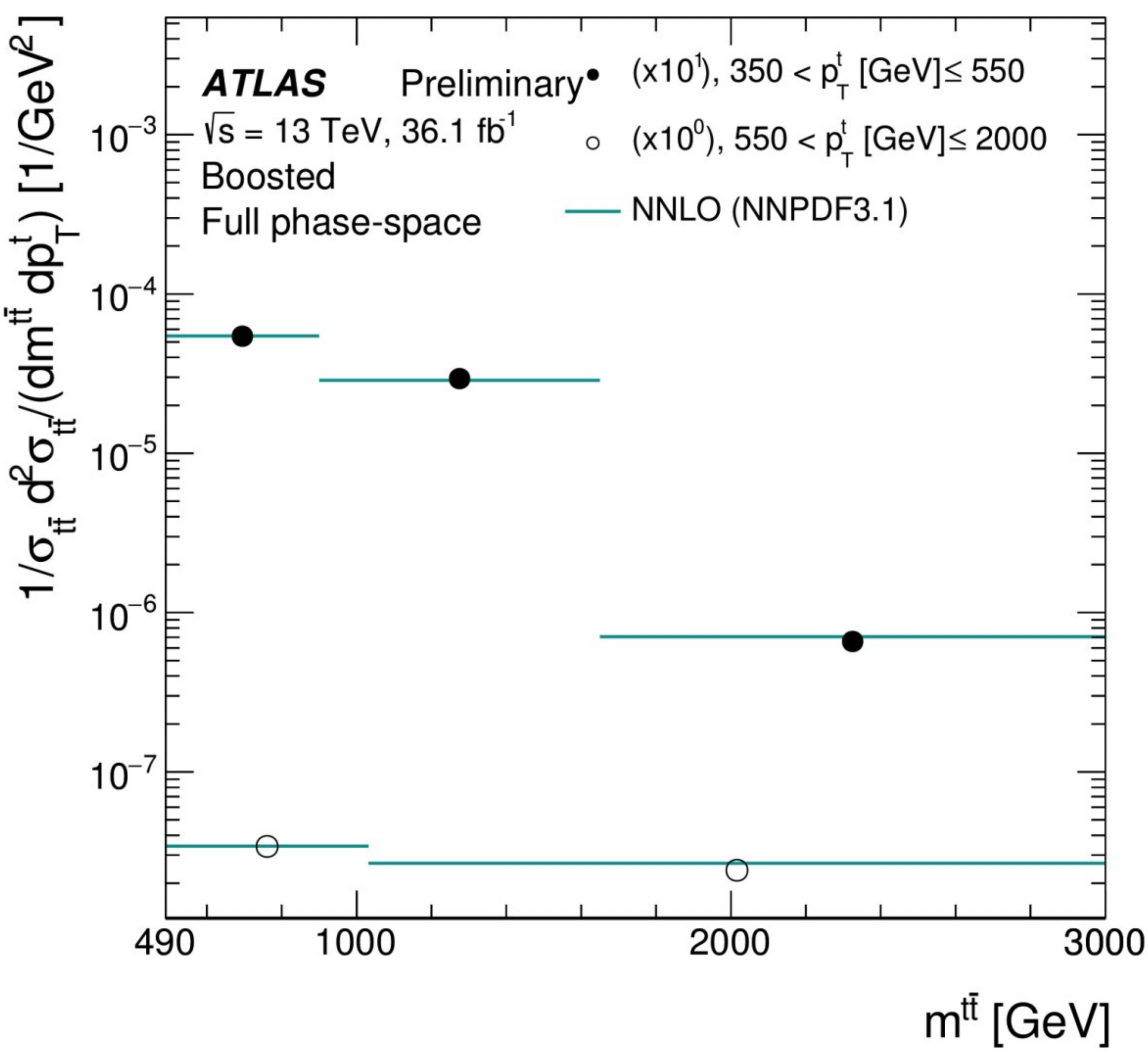

Figure 2: Top-quark-pair differential cross section as a function of the invariant mass of the top-quark pair and the transverse momentum of the top quark, as measured by ATLAS at 13 TeV using events in the single-lepton channel, are compared to the theoretical prediction from next-to-next-to-leading order (NNLO) calculations. Credit: ATLAS Collaboration/CERN

ATLAS' new precise measurement of the top-quark-pair cross section has also been used to pin down several parameters – including the top-quark mass to $m_t = 173.1 \pm 2.1$ GeV – and to constrain the "parton distribution functions" that characterise the internal structure of the proton in terms of its constituent quarks and gluons.

The energies and angular distributions of the produced leptons (i.e. their "kinematics") have also been precisely measured. These were compared to predictions from various "event generator" programmes, used to model top-quark events at the LHC. ATLAS physicists noted several discrepancies, pointing to the need for more precise theoretical calculations to better describe the observed lepton momentum distributions.

Going one step further, another new ATLAS result delved deeper into the kinematics of the top quarks themselves. For the first time in ATLAS, the rate of top-quark-pair production has been measured as function of two kinematic variables simultaneously (2D distributions, see Figure 2).

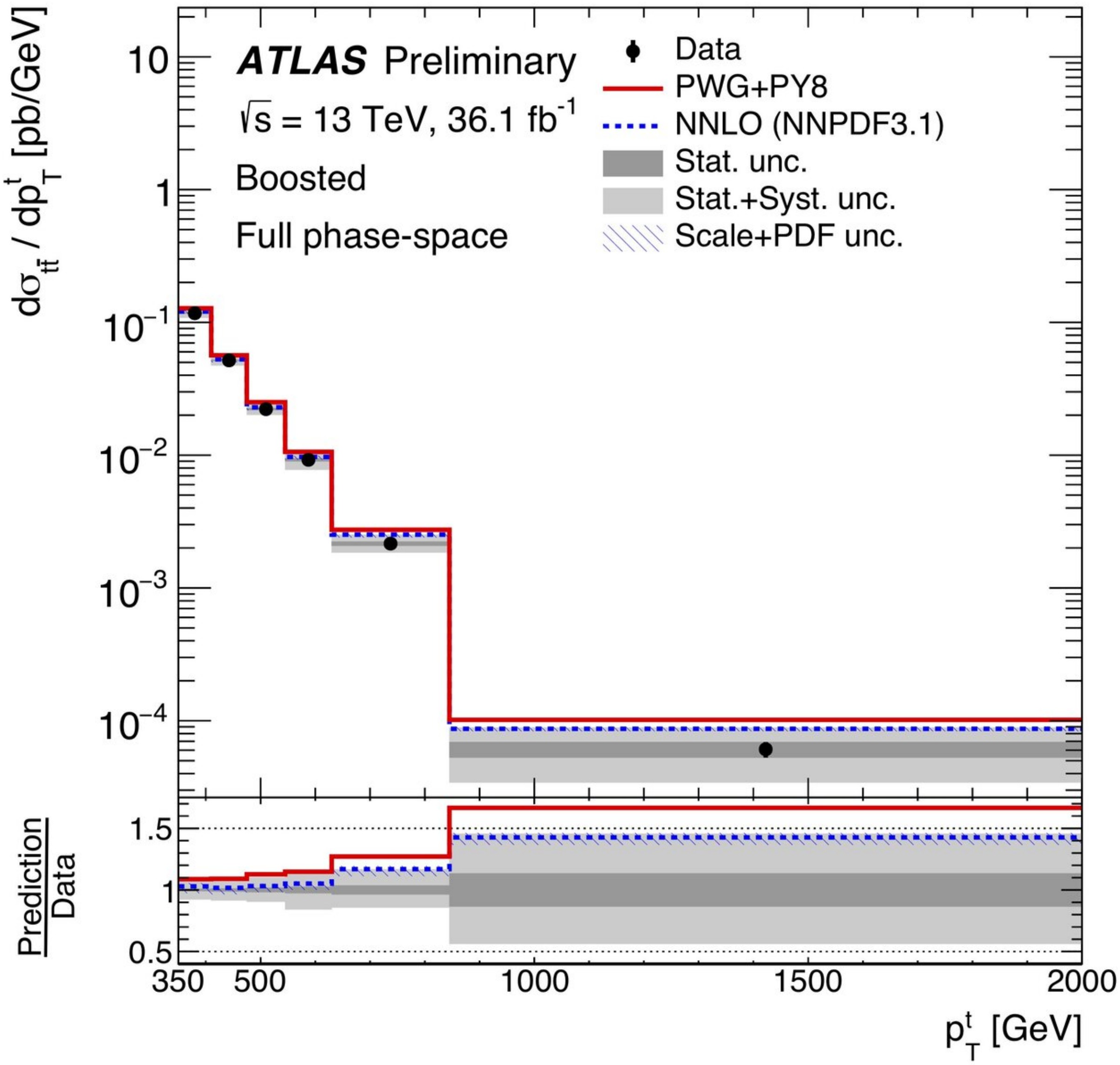

Figure 3: Top-quark-pair differential cross section as a function of the transverse momentum of the top quark, using 13 TeV events in the single-lepton channel. This is compared to theoretical predictions from the Powheg+Pythia8 event generator and fixed-order NNLO calculations. The lower plot shows the ratio between the predictions and the measurement. Credit: ATLAS Collaboration/CERN

To accomplish this, physicists selected top-quark-pair events where one top quark decays to a lepton, a neutrino and a b-quark, while the other decays to a b-quark and quark-antiquark pair. Studies of this final state, referred to as "single-lepton" channel, allowed ATLAS teams to reconstruct more precisely the kinematics of the top-quark-pair, including in cases where "boosted" top quarks with extremely high transverse momentum relative to the collision axis are produced. These are of key interest to new physics searches as massive exotic particles could decay into two highly-boosted top quarks.

Physicists compared the measured distributions to the latest theoretical calculations, with improved production-rate estimates in high-momentum regimes. The results show that theoretical calculations predict more top quarks at very high momentum than are observed (Figure 3). This confirms and improves upon previous measurements published by both the ATLAS and CMS experiments. Moreover, thanks to the shape of the 2D distribution, the top-quark-pair production rate as a function of the invariant mass and the top-quark transverse momentum can be used for future measurements to measure the top-quark mass.

Taken together, these two new results provide a wealth of data to improve our understanding of top-quark-pair production, and to further pin down the properties of this heavyweight particle.

More information: Measurement of the inclusive and lepton differential distributions in dilepton tt events in proton-proton collisions at 13 TeV with the ATLAS detector (ATLAS-CONF-2019-041): atlas.web.cern.ch/Atlas/GROUPS … ATLAS-CONF-2019-041/

Provided by ATLAS Experiment