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Observation of top-quark pair production in p+Pb collisions in the ATLAS experiment

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Top quarks, the heaviest elementary particles carrying colour charges, are considered to be attractive candidates for probing the quark-gluon plasma produced in relativistic heavy-ion collisions. In proton-lead collisions, top-quark production is expected to be sensitive to nuclear modifications of parton distribution functions at high Bjorken-x values, which are difficult to access experimentally using other available probes. In 2016, the ATLAS experiment recorded proton-lead collisions at a centre-of-mass energy of 8.16 TeV per nucleon pair, corresponding to an integrated luminosity of 165 nb^{-1}. In these proceedings, the final measurement of the top-quark pair production in dilepton and lepton+jet decay modes in the proton-lead system with the ATLAS detector is presented. The inclusive cross-section is extracted using a profile-likelihood fit to data distributions in six signal regions. The nuclear modification factor is also measured, and the measurements are found to be in good with theoretical predictions using nuclear parton distribution functions. The relative uncertainty amounts to 9%, making it the most precise top-quark pair cross-section measurement in heavy-ion collisions.

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1. Introduction

The observation of top-quark pair production in proton-lead (p+Pb) collisions provides a new probe to study nuclear parton distribution functions (nPDFs) and their modification in nuclear matter. These studies offer insight into parton dynamics at high Bjorken-x and high Q^2, which are crucial for understanding gluon distributions inside nuclei. Additionally, top quarks, due to their large mass, serve as valuable probes of the quark-gluon plasma (QGP) in ultra-relativistic heavy-ion collisions [1].

2. Experimental setup

The ATLAS detector at the LHC is a general-purpose detector designed to explore a wide range of physics phenomena. It has nearly full 4π coverage and includes the Inner Detector (ID), electromagnetic and hadronic calorimeters, and a muon spectrometer [2]. The data, collected in 2016, correspond to 165 nb^{-1} of p+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV. Electrons and muons with $p_{\mathrm{T}} > 18$ GeV were selected, and jets are reconstructed using the anti-k_{t} algorithm with a radius parameter $R = 0.4$. The b-jets from top-quark decays were identified using the DL1r algorithm [3], a multivariate discriminant based on deep-learning techniques making use of track impact parameters and reconstructed secondary vertices.

3. Event selection and signal and background modelling

The analysis focuses on two key channels, as explained in the following., Lepton+jets: one high-p_{T} lepton (electron or muon) and at least four jets, with and at least one b-tagged jet. This channels is split into 1ℓ1b, 1ℓ2b inclusive regions for e+jets and μ+jets [1]. Dilepton: two opposite-sign leptons and at least two jets and at least one b-tagged jet. This channel has higher purity and is categorised into 2ℓ1b and 2ℓ2b inclusive [1]. Fake-lepton backgrounds are estimated from data using a technique called the matrix method [4].

Monte Carlo (MC) samples for signal modelling were generated using Powheg Box v2, interfaced with Pythia 8 for parton-shower modelling [1]. Systematic uncertainties were assessed using Herwig v7.2. Backgrounds from W+jets, Z+jets, single top, and diboson processes were modelled with Sherpa v2.2.10. The $t\bar{t}$ cross-section in proton-lead collisions is affected by nuclear effects like anti-shadowing and the EMC effect, which modifies the gluon distributions in nuclei. These were modelled using next-to-next-to-leading-order (NNLO) QCD calculations with nPDF sets such as EPPS21 and nNNPDF30 [1].

4. Results

The top-quark pair production cross-section was measured in both the lepton+jets and dilepton channels. The inclusive cross-section for $t\bar{t}$ production was found to be:

$$\sigma_{t\bar{t}} = 58.1 \pm 2.0\,(\text{stat.})^{+4.8}_{-4.4}\,(\text{syst.})\,\text{nb}.$$

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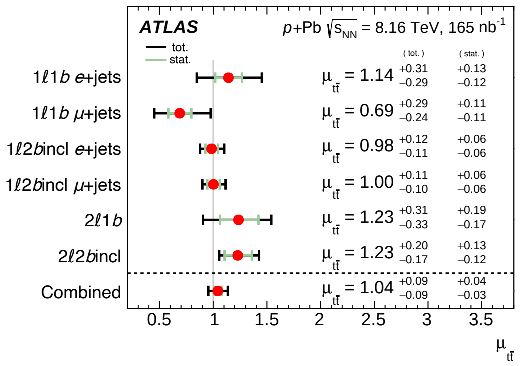
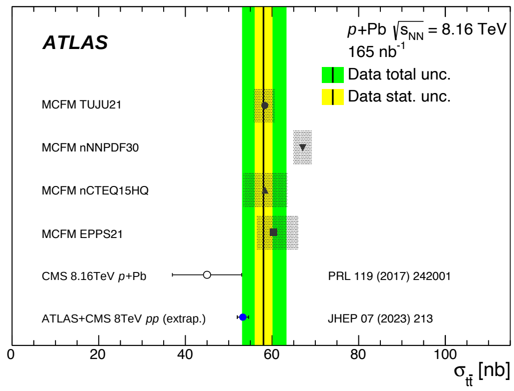
The nuclear modification factor, R_{pA}, was measured for the first time at the LHC for $t\bar{t}$ production:

$$R_{pA} = 1.090 \pm 0.039\,(\text{stat.})^{+0.094}_{-0.087}\,(\text{syst.}).$$

This result is consistent with theoretical predictions and indicates a slight enhancement in $t\bar{t}$ production in proton-lead collisions relative to proton-proton collisions. The measured $\mu_{t\bar{t}}$ value, representing the signal strength (ratio of observed to expected cross-section), is 1.04 ± 0.09 for the combined analysis of all channels; the results of the individual channels are shown in Figures 1a and 1b.



(a)



(b)

Figure 1: (a) Signal strength values in different channels, and (b) comparison of theoretical predictions using different nPDF sets with the measured cross-section [1].

The results were also compared to previous measurements by the CMS collaboration, which observed $t\bar{t}$ production in p+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV with a lower precision [5].

5. Conclusion

The observation of top-quark pair production in p+Pb collisions at the LHC opens a new avenue for studying nuclear parton distributions in a poorly constrained kinematic region. The measured nuclear modification factor, R_{pA}, provides insight into the nuclear gluon distribution at high Bjorken-x. These results also serve as a crucial baseline for future studies of top-quark production in Pb+Pb collisions, where top quarks can be used as a probe of the QGP.

References

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