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ATLAS search strategy for single-top production

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Summary. — The search strategy of the ATLAS experiment for single top quark production during the first two years of data-taking at the LHC is presented. The study focuses on the dominant t-channel production process, assuming an integrated luminosity of $200\,\text{pb}^{-1}$ at a center-of-mass energy of 10 TeV. An artificial neural network is employed to control background from $t\bar{t}$ production and W boson production in association with jets. Single-top sensitivities obtained with a sequential cut analysis and a robust likelihood ratio discriminant are compared.

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1. – Introduction

The ATLAS experiment [1] at the CERN Large Hadron Collider (LHC) has started data-taking at a center-of-mass energy of $\sqrt{s} = 7\,\text{TeV}$ in March 2010. Top quark physics plays a key role at the LHC, both as an interesting signal and as a major background to searches for the Higgs boson and physics beyond the standard model (SM). The ATLAS top physics program for the data-taking period 2010/2011 includes measurements of the production cross section both for QCD production of $t\bar{t}$ pairs and electroweak single t production. Studying single t production, which was first observed at the Tevatron in 2009 [2], allows for a direct measurement of the CKM matrix element V_{tb} and searches for heavy W' bosons, charged Higgs bosons, and anomalous t production via flavor-changing neutral current processes.

At the LHC, all three single top quark production channels have sizable cross sections. The dominant process is t-channel production ($\sigma_{t\text{-chan}} = 124.5\,\text{pb}$ at $\sqrt{s} = 10\,\text{TeV}$), followed by Wt associated production ($\sigma_{Wt} = 32.7\,\text{pb}$) and s-channel production ($\sigma_{s\text{-chan}} = 6.6\,\text{pb}$). This study presents the ATLAS search strategy for single t production in early LHC data, restricted to the dominant t-channel [3, 4]. The analysis is based on Monte Carlo (MC) simulated data and assumes a data sample corresponding to $200\,\text{pb}^{-1}$ of integrated luminosity at $\sqrt{s} = 10\,\text{TeV}$. The major background processes include $t\bar{t}$ production, W boson production in association with jets (W + jets), and QCD multijet production.

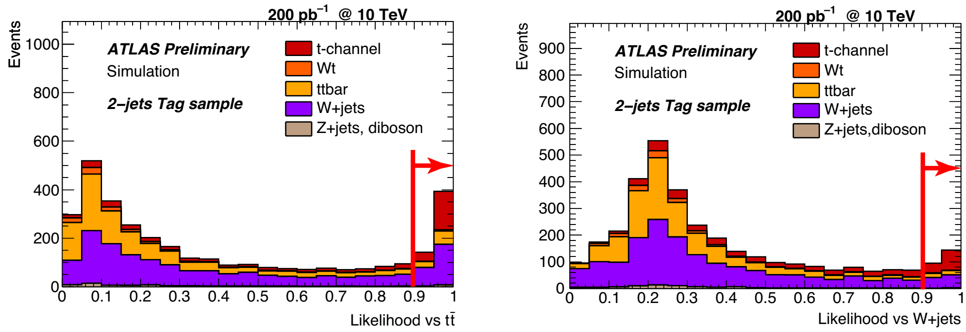

Fig. 1. – Distribution of likelihood ratio discriminants to reject $t\bar{t}$ (left) and $W+\text{jets}$ (right) background assuming $200\,\text{pb}^{-1}$ of data at $\sqrt{s}=10\,\text{TeV}$.

2. – Common event selection and background determination

Candidate events are selected by a pre-selection common to all single t production channels that requires exactly one isolated $e^{\pm}$ or or $\mu^{\pm}$ with large transverse momentum ($p_{\text{T}} > 20\,\text{GeV}$), 2–4 high-$p_{\text{T}}$ jets ($p_{\text{T}} > 30\,\text{GeV}$), one of which with a secondary vertex b-tag, and missing transverse energy $E_{\text{T}}^{\text{miss}} > 30\,\text{GeV}$. QCD multijet background is rejected based on the transverse mass reconstructed from the lepton and $E_{\text{T}}^{\text{miss}}$: $m_{\text{T}} > 30\,\text{GeV}$.

The $t\bar{t}$ and $W+\text{jets}$ background rates are determined using a control region in data. While the signal region includes two jets with ≥ 1 b-tags, the control region contains all three-jet events before b-tagging. A neural network (NN) is trained to separate the t-channel signal from the $t\bar{t}$ and $W+\text{jets}$ background, using, *e.g.*, H_{T} ($\sum p_{\text{T}}$ of all jets, the lepton, and $E_{\text{T}}^{\text{miss}}$), various two- and three-jet invariant masses and lepton-jet angles. The background rates are extracted from a template fit to the NN discriminant in the control region and extrapolated to the signal region assuming that the ratio of events in the signal and control regions is modeled correctly in the MC simulation. A systematic uncertainty of 7% (14%) for background from $t\bar{t}$ ($W+\text{jets}$) production is assigned.

3. – Measurement of the production cross section in the t-channel

Two robust methods are employed to extract $\sigma_{t\text{-chan}}$: a sequential cut analysis and a likelihood analysis. The sequential cut analysis explores two characteristics of the t-channel process, a very forward ($|\eta| > 2.5$) light-flavor jet and a high-p_{T} b-jet ($p_{\text{T}} > 50\,\text{GeV}$) from the decay of the t quark. Likelihoods are defined for the signal ($\mathcal{P}_{\text{sig}}$) and for the $t\bar{t}$ and $W+\text{jets}$ backgrounds ($\mathcal{P}_{\text{bkg}}^{t\bar{t}}$, $\mathcal{P}_{\text{bkg}}^{W+\text{jets}}$). Two likelihood ratios $\mathcal{L} = \mathcal{P}_{\text{sig}}/(\mathcal{P}_{\text{sig}} + \mathcal{P}_{\text{bkg}}^{t\bar{t},W+\text{jets}})$ are used to discriminate t-channel single top production from $t\bar{t}$ and $W+\text{jets}$ production. To reduce the sensitivity to uncertainties in the jet energy scale (JES) all likelihoods are constructed only from angular variables, *e.g.* $|\eta|$ of the highest-p_{T} non-b-tagged jet and centrality $C = \sum p_{\text{T}}/\sum E$, where the sums are over all jets and leptons. The likelihood ratio discriminants are shown in fig. 1. The signal region is defined as all events in which $\mathcal{L} > 0.9$ is fulfilled for both discriminants.

The sample is divided into four individual final states with $e^{\pm}$ and $\mu^{\pm}$ and $\sigma_{t\text{-chan}}$ is extracted from a maximum likelihood fit to all four final states. In the signal region

TABLE I. – *Sources of statistical and systematic uncertainty for the measurement of the single-top production cross section in the t-channel with* $200\,\mathrm{pb}^{-1}$ *of data at* $\sqrt{s} = 10\,\mathrm{TeV}$.

Source	Variation	Sequential	Likelihood
Data Statistics		15%	14%
MC Statistics	Limited MC Sample Size	6%	6%
Jet Energy Scale	±5% per Jet	8%	3%
b-Tagging	±6% Tagging Eff., ±10% Mistag Rate	26%	22%
Background Norm.	Fit to NN Output (3 jets, before b-tag)	12%	10%
ISR/FSR	AcerMC + Pythia Parameters	10%	10%
PDFs	CTEQ6m – CTEQ66 – MRST2006nnlo	7%	6%
MC Generators	AcerMC – MC@NLO	11%	16%
Lepton ID & Trigger	±1% per Lepton	4%	3%
Luminosity	±10%	11%	11%
Total		45%	40%

(two jets, at least one b-tag), an expected signal-to-background ratio of $S/B = 0.64$ is obtained for the sequential cut analysis, while the likelihood ratio analysis reaches $S/B = 0.89$, with only 5% fewer signal events passing the selection than in the sequential cut analysis.

4. – Single-top sensitivity

The expected sensitivity for t-channel single t production assuming the SM cross section is extracted from ensemble tests. The ensemble tests consist of many pseudo-experiments which include systematic uncertainties for signal acceptance and background rates as nuisance parameters with Gaussian shapes. All sources of uncertainty considered in this study are listed in table I. The cross section limits and the single-top sensitivity are extracted using a Bayesian approach, resulting in an expected sensitivity of 2.7σ.

In summary, ATLAS has developed a strategy to search for t-channel single top quark production in early data. With a likelihood ratio analysis, the production cross section can be measured with 40% precision at $S/B = 0.9$ using $200\,\mathrm{pb}^{-1}$ of data at $\sqrt{s} = 10\,\mathrm{TeV}$. The measurement is systematics-limited even in early data-taking; the largest systematic uncertainty originates from b-tagging. Assuming the SM value of $\sigma_{t\text{-chan}}$ a sensitivity of 2.7σ is expected. With all cross sections reduced by approximately a factor of two for the current data-taking at $\sqrt{s} = 7\,\mathrm{TeV}$, evidence for single-top production at ATLAS is in reach with the 2010/2011 data sample.

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