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Measure of the $t\bar{t}$ pair production cross-section at ATLAS

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Summary. — An accurate determination of the top quark pair production cross-section at the LHC provides a valuable check of the Standard Model. Given the high statistics which will be available, this check can be performed relatively fast after the turn-on of the LHC. Here are presented the prospects for measuring the total top pair cross-section with the ATLAS detector during the initial period of LHC running. The cross-section is determined in the semi-leptonic channel, and in the di-leptonic channel, using both counting and fit methods.

PACS `29.85.Fj` – Data analysis.

1. – Introduction

The top quark, discovered at Fermilab in 1995 [1], completed the three-generation structure of the Standard Model and opened up the new field of top quark physics. Produced predominantly, in hadron-hadron collisions, through strong interactions (*i.e.* in top-antitop pairs), decays rapidly without forming hadrons, and almost exclusively through the single mode $t \to Wb$. The W boson can then decay leptonically (in 1/3 of the cases into a charged lepton ℓ and a neutrino ν) or hadronically (in 2/3 of the cases into a quark-antiquark pair). From an experimental point of view, depending on the decays of the two Ws, the following signatures can be identified:

- Di-leptonic (about 1/9 of the cases): both Ws decay leptonically, resulting in an event with two ℓs, two νs and two b-jets; this mode allows a clean sample of top events to be obtained, but has limited use in probing the top reconstruction capability of the ATLAS experiment, due to the two νs escaping detection.
- Fully hadronic (about 4/9): both Ws decay hadronically, which gives six jets in the event; in this case, we do not have a high-p_T ℓ to trigger, the signal is not easily distinguishable from the abundant QCD multi-jets production, and there is a high combinatorial background when reconstructing the top mass.
- Semi-leptonic (about 4/9): the presence of a single high-p_T ℓ allows to suppress the $W+$jets and QCD background and the p_T of the ν can be reconstructed as it is the only source of missing E_T for signal events; this is the most useful channel at ATLAS.

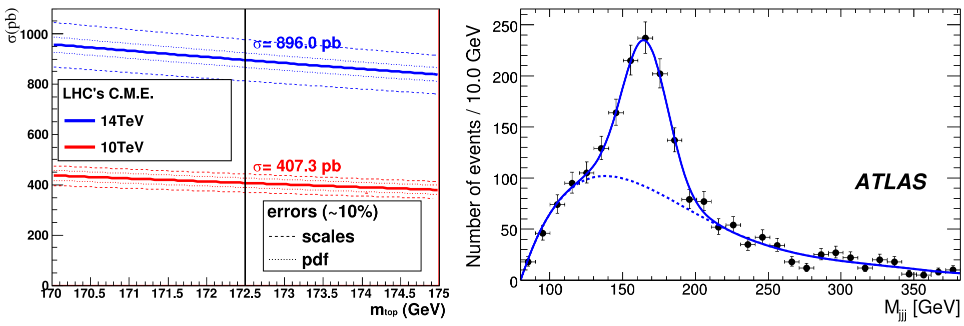

Fig. 1. – Left: NLO+NLL total $t\bar{t}$ cross-section at the LHC, as a function of $m_{\rm top}$ and for c.m.e. of 10 and 14 TeV, using CTEQ6M PDF set. The indicated values are for $m_{\rm top} = 172.5$ GeV. Right: likelihood fit method, for the semi-leptonic channel. To extract the number of completely reconstructed $t\bar{t}$ events, a maximum likelihood fit is performed to the three-jet mass distribution, with a Gaussian signal on top of the background described by a Chebychev polynomial.

Measuring the top-pair production cross-section will allow to perform a direct comparison with a theoretical calculation. On top of that, $t\bar{t}$ events are also an important background for the new phenomena and for the Higgs searches. Last but not least, the top pair production process will be valuable for the *in situ* calibration of the ATLAS detector during the commissioning phase: understanding the experimental signatures of top events involves most parts of the ATLAS detector and is essential for claiming discoveries of new physics.

The only collider where until now the top quark has been produced is the Tevatron, where it is produced from $p\bar{p}$ collisions at a center-of-mass energy of 1.92 TeV. The latest measures of the total $t\bar{t}$ production cross-section from CDF and DØ [2] are in good agreement with the theoretical predictions [3], and their experimental errors are of the order of the theoretical one. The theoretical predictions for the LHC are illustrated in fig. 1 (left) [3], and all have uncertainties of the order of 10%.

All the analysis has been studied and tested, including the systematics, using Monte Carlo samples produced with different event generators for signal and background processes and processed with the full simulation of the ATLAS detector. All has been simulated for a center-of-mass energy of 14 TeV and the numbers and the plots are referred to an integrated luminosity of 100 pb^{-1}.

For a more detailed description see the top chapter of ATLAS CSC note [4].

2. – Semi-leptonic channel

The base selection, for semi-leptonic events, is based on the topological and kinematical properties of their final states. The events are required to fulfil the following:

– one lepton (e or μ) with $p_T > 20$ GeV (witch gives the isolated lepton trigger),

– missing $E_T > 20$ GeV (associated to ν coming from the leptonically decaying W),

– at least four jets with $p_T > 20$ GeV (two coming from the hadronically decaying W and two b-jets produced directly in top and antitop decays),

– of which at least three jets with $p_T > 40$ GeV.

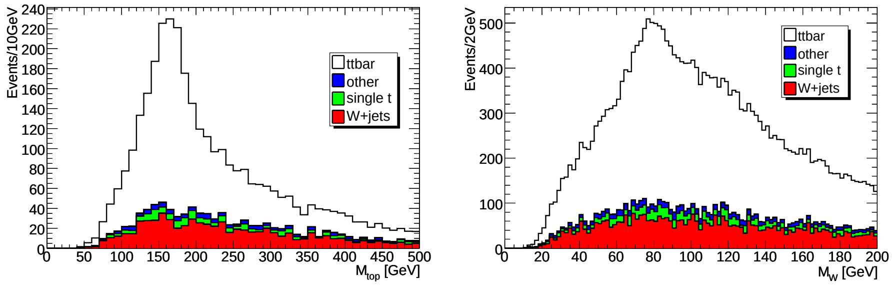

Fig. 2. – (Colour on-line) Top candidate mass (left) and di-jet mass distribution inside the top candidate (right). The white histograms refer to the signal events, while the colored ones to the main backgrounds. Both the top mass peak around 175 GeV and the W mass peak around 80 are clearly visible, even with a large combinatorial background component.

These cuts are chosen to maximize the signal significance $S/\sqrt{S+B}$, where S and B are the number of signal (in our case semi-leptonic $t\bar{t}$) and background events passing the selection.

The main backgrounds surviving the base selection are expected to be: the $W+\text{jet}$ production (witch is dominant), the single top electroweak production, the $Z+\text{jets}$, the diboson events (WW, WZ or ZZ), the other two $t\bar{t}$ decay channels and the QCD multi-jet production. After the base selection, the signal purity S/B is about 2.2.

A second important step in event reconstruction consists in testing the events for compatibility with a $t\bar{t}$ hypothesis. A top-quark decay candidate is defined as the three-jet combination of all jets that has the highest transverse vector sum momentum. Figure 2 (left) shows the reconstructed top mass for this selection (from now on referred as top candidate).

Even in the $t\bar{t}$ hypothesis, two of the three jets, combined to form the top candidate, come from the decay of W boson. In fig. 2 (right) the invariant mass of all the three possible di-jet combinations inside the top candidate are shown.

To increase the purity of the top sample S/B, the first additional selection consists on requiring that at least one of the three di-jet invariant masses is within 10 GeV of the reconstructed mass of the W. This selection is referred as the W mass constraint selection, and increases the purity by a factor of 1.5.

Then, a couple of further selections have been studied to further increase the purity, for example require the top candidate invariant mass in a top mass window and/or the use of b-tagging information. With all these requirements, a signal purity of about 20 is reachable.

The $t\bar{t}$ cross-section can be obtained by performing a counting experiment, *i.e.* evaluating $\sigma = \frac{N_{\text{sig}}}{L\times\epsilon} = \frac{N_{\text{obs}}-N_{\text{bkg}}}{L\times\epsilon}$. The number of background events N_{bkg}, estimated from Monte Carlo simulations and/or data samples, is subtracted from N_{obs}, the number of observed events meeting the selection criteria of a top-event signature. This difference is divided by the integrated luminosity L and the total efficiency ϵ. The advantage of using event counts in the commissioning phase is that, early on, the Monte Carlo simulations may not predict the shapes of distributions very well.

A second method, called likelihood fit, is illustrated in fig. 1 (right). One of his biggest advantage, consists in his capability of extracting both the signal's and background's

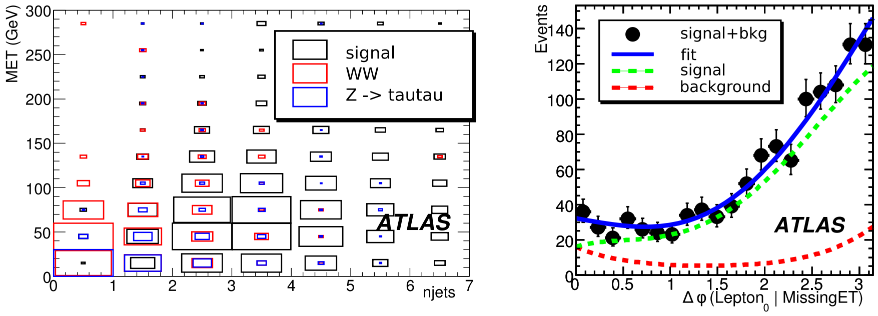

Fig. 3. – Inclusive template (left) and likelihood (right) fit methods, for the di-leptonic channel. The first one consists in building a two-dimensinal template in the E_T *vs.* the number of jets plane, to extract the number of signal and background events. The second one uses the different distribution of signal and background in the one-dimensional histogram of $\Delta\phi$ between the missing E_T vector and the highest p_T lepton (or jet).

number of events. Two of the major disadvantage are the need of a bigger statistic to build the distribution, and the uncertainties coming from the shape of fitting functions.

Both the measurement methods give a total $\Delta\sigma/\sigma \simeq$ 15–20%, with the systematics dominated, for the counting method, by the jet energy reconstruction uncertainity and, for the likelihood method, by the shape of the fitting functions.

3. – Di-leptonic channel

The base event selection for di-leptonic $t\bar{t}$ events starts from the identification of two high-p_T opposite-signed leptons, *i.e.* two e, two μ, or one e and one μ, with $p_T > 20\,\text{GeV}$. Then, the presence of at least two reconstructed jets with $p_T > 20\,\text{GeV}$ is required.

The main backgrounds to the $t\bar{t}$ di-lepton signal include $Z+$jets, $W+$jets, dibosons, single-top and semi-leptonic $t\bar{t}$. To reduce them, additional kinematical cuts are performed on the missing E_T distribution, requiring it to be greater than 30, 35 or 25 GeV for the $\ell\ell$, $ee/\mu\mu$ or $e\mu$ channels, respectively, and on the di-lepton invariant mass, vetoing a window of 10 GeV around the Z mass peak. After these selections, the signal purity is about 5 for each channel.

Like in the semi-leptonic channel, the cross-section can be extracted using either a counting method (see previous section) or with a fit method. There are two proposed fit methods, illustrated in fig. 3. The same considerations of the semi-leptonic case can be applied about the advantage and the disadvantage of each method. With all the proposed methods, a $\Delta\sigma/\sigma \simeq 10\%$ is reached.

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