IL NUOVO CIMENTO Vol. 35 C, N. 3 Maggio-Giugno 2012
DOI 10.1393/ncc/i2012-11241-6

Colloquia: TOP2011

# Search for same-sign top production at the LHC

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ricevuto l' 1 Marzo 2012
pubblicato online il 4 Giugno 2012

**Summary.** — An inclusive search for same-sign top-quark pair production in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ is performed using data samples recorded with the ATLAS and CMS detectors at the Large Hadron Collider. These searches are motivated by the hypothesis of Flavor Changing Neutral Currents (FCNC) in the top sector, which would imply enhancement of same-sign top-pair production in pp or p$\bar{\text{p}}$ collisions by the exchange of a hypothetical massive Z′ boson. As no excess of events is observed, the ATLAS and CMS analyses constrain the FCNC models as a function of the mass the Z′ boson and its couplings. The observed limits disfavor the FCNC interpretation of the Tevatron results and limits are set on the cross section of same-sign top production at the Large Hadron Collider.

PACS 14.65.Ha – Top quarks.

## 1. – Introduction

Searches for same-sign top pair production at the Large Hadron Collider are motivated by the Tevatron measurements of the forward-backward t$\bar{\text{t}}$ asymmetry ($A_{FB}$) which deviate from the standard model (SM) expectations [1, 2]. Many of the attempts to explain this asymmetry predict the existence of Flavor Changing Neutral Currents (FCNC) in the top-quark sector, mediated by the exchange of a new massive Z′ boson. Some models also incorporate an explanation for the anomalous dijet invariant mass distribution reported by the CDF collaboration in p$\bar{\text{p}} \to \text{W} + 2$ jets [3]. A consequence of such FCNC models would be an excess in the production of same-sign top quark pairs at the LHC. This report summarizes recent searches for anomalous tt production by the ATLAS and CMS experiments [4, 5].

## 2. – Theory motivation and analysis strategy

An effective model of u-t-Z′ interaction term in the Lagrangian would be

$$\mathcal{L} = g_W \bar{\text{u}}\gamma^\mu (f_L P_L + f_R P_R)\text{t}{\text{Z}'}_\mu + \text{h.c.}, \tag{1}$$

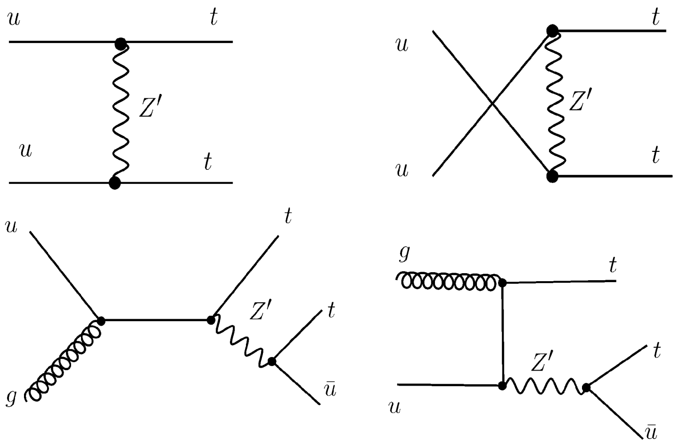


Fig. 1. – Diagrams for tt and ttj production in the presence of a Z′.

where $g_W$ is the weak coupling strength, and $P_L$ and $P_R$ are the left-handed and right-handed projection operators. The left-handed coupling is experimentally constrained to $f_L \approx 0$, because of $\mathrm{B_d}$-$\bar{\mathrm{B}}_\mathrm{d}$ mixing constraints. This leaves the right-handed coupling $f_R$ and the Z′ mass ($M_{Z'}$) as the only free parameters of such an effective model. The abundance of u quarks in the pp collisions at the LHC means that such an exchange would result in final states where two t (not two $\bar{\mathrm{t}}$) quarks are produced, as is shown by the Feynman diagrams in fig. 1.

Both ATLAS and CMS examine the topology where both top quarks decay as $\mathrm{t} \to \mathrm{W}^+\mathrm{b}$ followed by $\mathrm{W}^+ \to \ell^+\nu$. Events containing two high-$p_T$, prompt, like-sign leptons are rare, providing a low background for a search. The remaining backgrounds can be divided into three categories: SM production of real like-sign prompt lepton pairs, such as production of two or three gauge bosons, these processes are rare and are taken from simulation models; SM production of opposite-sign prompt lepton pairs where the charge of one of the leptons is mis-measured, the contribution of these processes can be modeled by simulation controlled by data-driven methods; and backgrounds from SM processes containing *non-prompt*, same-sign leptons originating from hadronic decays which are mis-identified as prompt leptons. It is impossible to create hadronization models detailed enough to predict these fake prompt leptons accurately and as very large samples are necessary, this contribution is more reliably measured from data.

## 3. – CMS measurement

The CMS analysis concentrates on the di-lepton final state where both top quarks decay as $\mathrm{t} \to \mathrm{W}^+\mathrm{b}$ followed by $\mathrm{W}^+ \to \ell^+\nu$, where $\ell = \mathrm{e}$ or $\mu$. Thus, the final state of interest contains two high transverse momentum ($p_T$) isolated positive leptons (e or $\mu$), two or more particle flow jets reconstructed with an anti-$k_T$ algorithm with $R = 0.5$, and missing transverse energy (MET) from two neutrinos [6, 7].

The 2010 dataset, equivalent to an integrated luminosity of $35\,\mathrm{pb}^{-1}$, is examined for events with same-sign leptons, where leptons are required to have $|\eta| < 2.4$, where $\eta$ is the pseudo-rapidity defined as $\eta = -\ln[\tan(\theta/2)]$, $\theta$ being the angle between the particle

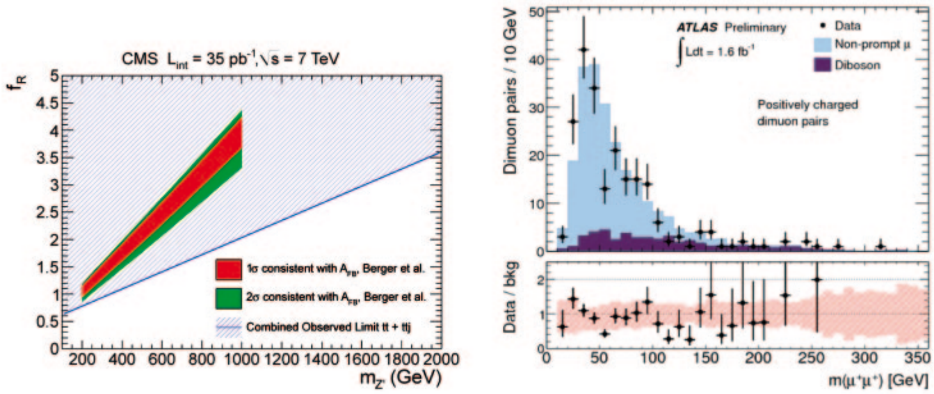


Fig. 2. – Left: CMS limits on the cross section for FCNC Z′ production. Effective field theory models consistent with the Tevatron $A_{FB}$ measurements are disfavored. Right: ATLAS di-muon invariant mass distribution for $\mu^+\mu^+$ pairs. The bottom plot shows the ratio of the data to the background prediction and the total uncertainty on the prediction. An additional data event is beyond the $x$-axis scale of the figure at 492 GeV.

momentum and the beam axis. The transverse momentum is required to be $p_T > 20\,\text{GeV}$, but in $ee$ and $\mu\mu$ events an additional $p_T$ requirement of 30 GeV is applied to the leading lepton due to trigger requirements. Additional quality cuts are applied in the lepton selection to assure a sample rich in real prompt leptons from top pair production and low in non-prompt fake leptons. The two jets in the event need to pass jet identification quality criteria, and are required to have $p_T > 30\,\text{GeV}$ after jet energy corrections and $|\eta| < 2.5$.

After the full selection $0.9 \pm 0.6(\text{syst})$ events with equally charged leptons are expected in both the positive or negative sign selection. The number of observed positive sign events is 2, while 0 negative sign events are selected, so no excess of events is observed and the observed event counts can be used to set limits on the cross section.

Typical selection efficiencies for a Z′ boson are $(0.95 \pm 0.13)\%$, where the uncertainties are dominated by systematic uncertainties due to the lepton selection and jet energy scale calibration. The selection efficiency is independent of the mass of the Z′ boson. Using this method, the production cross section is limited to $\sigma(\text{Z}' \to \text{tt} + \text{X}) < 17.0\,\text{pb}$, ruling out the full parameter space consistent with the FCNC interpretation of Tevatron results (fig. 2(left)).

## 4. – ATLAS measurement

The ATLAS experiment investigates tt final states where both $W^+$ bosons decay to $\mu^+\nu$, examining all final states with two isolated positive muons [8]. Muon selection is driven by the trigger thresholds, leading to an asymmetric selection of $p_T > 20(10)\,\text{GeV}$ for the leading (other) muon, where at least one muon candidate is required to be inside the trigger acceptance $|\eta| < 2.4$ and the other inside the detector acceptance $|\eta| < 2.5$. Both muons are required to be isolated from other tracks and hadronic activity in the event

A data sample with an integrated luminosity equivalent to $1.6\,\text{fb}^{-1}$ is examined for $\mu^+\mu^+$ pairs, where a di-muon mass constraint is used to further reject backgrounds.

Figure 2 (right) shows the $M(\mu^+\mu^+)$ mass spectrum. The most sensitive limit is set for $M(\mu^+\mu^+) > 200\,\text{GeV}$, where $9.2^{+1.8}_{-1.7}$ events are expected and 9 events are observed. The observed number of events is consistent with expectations from Standard Model processes, leading to limits on the production cross section of $\sigma(\mathrm{Z}' \to \mathrm{tt} + \mathrm{X}) < 4.1$–$3.0\,\text{pb}$ for $M(\mathrm{Z}') = 100$–$200\,\text{GeV}$. In addition, limits are set on the production cross section for four-fermion Z′ production, for masses where $M(\mathrm{Z}') \gg 1\,\text{TeV}$. For this case the 95% confidence limit on the production cross section is $\sigma(\mathrm{Z}' \to \mathrm{tt} + \mathrm{X}) < 2.9\,\text{pb}$, providing the most stringent limit on same-sign top production at the large hadron collider.

## 5. – Conclusion

The ATLAS and CMS experiments are both providing stringent limits on same-sign top production at the LHC. When interpreted in the context of FCNC Z′ models consistent with Tevatron results, limits can be set as a function of the mass the Z′ boson and its couplings. The observed limits disfavor the FCNC interpretation of the Tevatron results, allowing both experiments to constrain the production cross section of $\sigma(\mathrm{Z}' \to \mathrm{tt} + \mathrm{X}) < 17\,\text{pb}$ (CMS, $35\,\text{pb}^{-1}$) and $\sigma(\mathrm{Z}' \to \mathrm{tt} + \mathrm{X}) < 2.9$–$4.0\,\text{pb}$ (ATLAS preliminary, $1.6\,\text{fb}^{-1}$).

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The author is supported by the Odysseus program of the Fonds Wetenschappelijk Onderzoek (FWO) in Flanders, Belgium.

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