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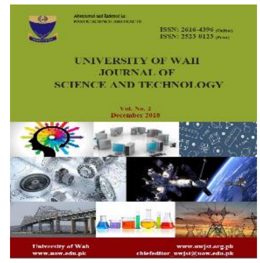

Top Quark Mass Measurement at TEVATRON and LHC Energies

Fakhra Ghafoor, Nameeqa Firdous, Fatima Ali and Wajeeha Khalid

***Abstract*—This research work provides a review of a well heaviest known quark i.e. Top Quark (a fundamental particle ever observed). In hadron collisions, it produces in particle-antiparticle combination, which provides an important probe of the strong interactions i.e. one of the four fundamental interactions. Top quark was discovered in 1995 at Fermi lab, with a mass that is about as heavy as an entire atom of gold, still remains a topic of intense research interest. The top quark mass is one of the key parameter of SM of Particle Physics. Its exact value effects directly to the key predictions of the SM including the production rates of top at the Large Hadron Collider (LHC). This study presents an overview of the top quark mass measurement at TEVATRON to LHC including the precise measurement of the top given by CMS (Compact Muon Solenoid) experiment at LHC.**

***Index Terms*—Standard Model (SM), Hadronization, Jet Scale Factor (JSF), Parton Distribution Function (PDF), Luminosity, Transfer Function, Top Quark, Compact Muon Solenoid (CMS).**

I. INTRODUCTION

IN Standard Model, Top Quark is known to be heaviest fundamental particle so far. It possesses unique features. In addition, its short lifetime makes it worth studying. Observed lifetime is $\sim 10^{-25}$ sec which is much shorter than the hadronization time. Top quark is also termed as bare quark as it does not exists in bound states due to its short lifetime and decays via W boson and a b quark in very short span.

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During Top Quark Run I, proton-antiproton ($p\bar{p}$) collision had been placed at 1.8 TeV. In 1995, CDF and DØ experiments discovered the top quark with $67\text{pb}^{-1}$and $50\ \text{pb}^{-1}$of integrated luminosity, respectively [1-4].

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In 2001, Run II started with 1.96 TeV, $p\bar{p}$ collisions with provision of approximately 10.5fb^{-1} of integrated luminosity. It also leads us towards Beyond Standard Model (BSM). In Past, different simulation techniques have been developed for mass measurement of top quark.

Whilst, Large Hadron Collider (LHC) at CERN is also known as top factory where proton proton (pp) collisions at center of mass energy (7 TeV) has delivered already more than 3fb^{-1} of data to ATLAS and CMS (Two general purpose detectors). Most dominant processes of top quarks production are $\bar{q}q \rightarrow t\bar{t}$ and $gg \rightarrow t\bar{t}$ [5-6].

At TEVATRON, quark-antiquark annihilation is dominant with 85% of production cross section measurement. Whereas gg fusion shows less dominant process with 15% production cross section measurement. While at LHC energies, gg fusion is dominant with 80% of the production at ($\sqrt{s} = 7$ TeV). Due to the high energy, the production rate of $t\bar{t}$ at LHC is much larger than at the TEVATRON [7, 8]. The large datasets at all main experiments like ATLAS and CMS enable us to measure top quark cross section production with high precision.

II. LITERATURE SURVEY

A. *Production of Top Quarks*

There exist many channels by which top quarks can be produced. *Figs. 1* and *2* show one of the most occurring channels of hadron colliders via strong interaction in which top anti-top is produced in pair [9, 10].

Alternative production via electroweak interaction involving a W_{tb} vertex. Top quarks produced in this way are often referred to as single top quark as shown in *Figs. 3* and *4*, which means only one top is produced. Additionally, single top quark events have a much larger background due to their lower jet multiplicity. These two factors make the search for single top quark far more difficult than that of top quarks produced by the strong interaction.

Three different mechanisms have been predicted by electroweak theory for the production measurements of single top quarks are t – channel, s – channel, $|V_{ts}|$ and $|V_{td}|$ vertex that has less probability to get top quark as a result.

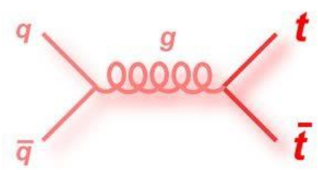

Fig. 1. Top Pair Production via quark-antiquark.

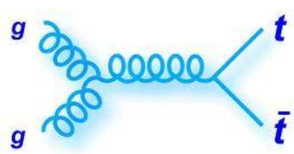

Fig. 2. Top Pair Production Via gg Fusion.

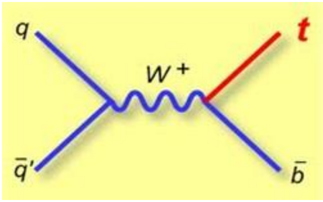

Fig. 3. (S-Channel Mode): single top quark.

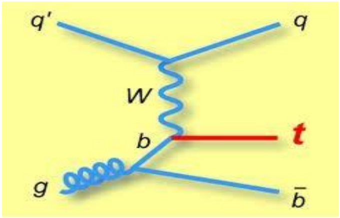

Fig. 4. (T-Channel Mode): single top quark.

B. *Decay modes of Top Quark*

The top disintegrates into W-boson and b-quark with nearly 100% branching fraction. There are two most familiar decay modes for $t\bar{t}$ production. One of the most important $t\bar{t} \rightarrow$ dilepton decay channel that is used in previous mass analysis at LEP as shown in *Fig. 5(a)*. During this interaction, both W bosons decay via lepton decay i.e. $t\bar{t} \rightarrow W^{-}bW^{+}\bar{b} \rightarrow \bar{l}\upsilon_{l}\bar{\upsilon}_{l}l^{+}b\bar{b}$. Only factors that

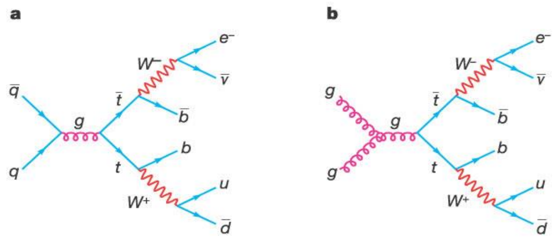

Fig. 5. Decay channels of top quark $\overline{qq}$ annihilation and gg fusion.

differentiate it from previous analysis are more weights assigned to more precisely measured events or that corresponds to $t\bar{t}$ signal (2). Final decay products (leptons and jets) and missing transverse momentum are hard enough to handle in identification of precise mass measurement. Also, because of leading order Matrix Element (ME) involvement to calculate the event weights.

Alternating way for the production of top pair includes (1 lepton, one missing energy and four jets)$t\bar{t} \rightarrow \bar{l}\upsilon_{l}q\bar{q}b\bar{b}$ used in ATLAS and CMS mostly.

III. RESULTS AND DISCUSSION

A. *Top-quark mass measurement at CMS Detector*

CMS is a general-purpose detector. Over the last years, the CMS collaboration has measured top-quark mass with high precision. All possible final products of the $t\bar{t}$ pairs are used to measure their production rate at both 7TeV and 8TeV center of mass energies. Many analyses have been carried for its mass measurement, which is explained as follows:

Top Pair channels:

- Di Lepton Channel
- SSemi Lepton Channel
- Fully Hadronic Channel

Single Top Channel:

- s-Channel
- t-Channe
- tW Associated Channel

In the Mass measurement of CMS,

$$t\bar{t} \rightarrow lepton + jets \quad (1)$$

$$t\bar{t} \rightarrow alljets \quad (2)$$

Where ideogram method is used in (1) and (2) channels and further kinematic fit is done on following decay modes:

$$t\bar{t} \rightarrow l\bar{v}q\bar{q}b\bar{b} \quad (3)$$

$$t\bar{t} \rightarrow q\bar{q}bq\bar{q}\bar{b} \quad (4)$$

For these ideograms, different likelihood functions are employed that depends on m_{top} and Jet Scale Factor (JSF) [11-12].

In $t\bar{t} \rightarrow$ dilepton channel, m_{top} is obtained from Matrix Element (ME) method, by reconstructing event kinematics [3].

with $4.7fb^{-1}$ cross section (i.e. 9% uncertainty attained) by CMS at 7 TeV. Most recent searches include 4.8% uncertainty for V_{tb} with highly précised measurement at 8 TeV from the tW-channel. Current work is done at 95% confidence level. By applying the likelihood fit technique, CMS measures $m_{top} = 173.3 \pm 0.76$GeV.

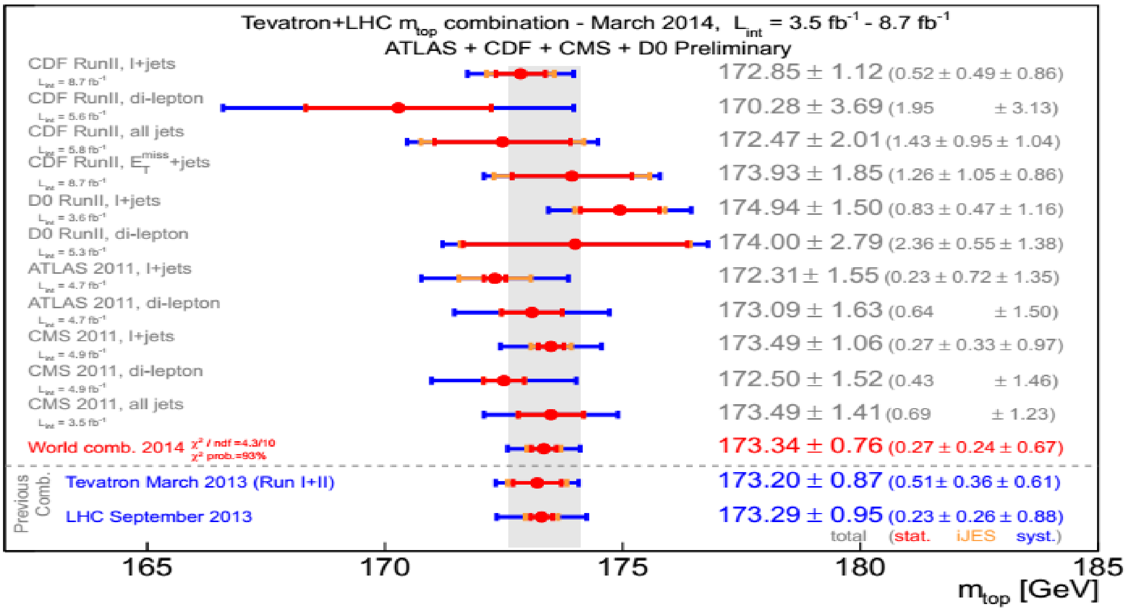

Fig. 6. Comparison of the m_t combination result with the individual m_t determinations as per $\bar{t}t$ decay channel [19].

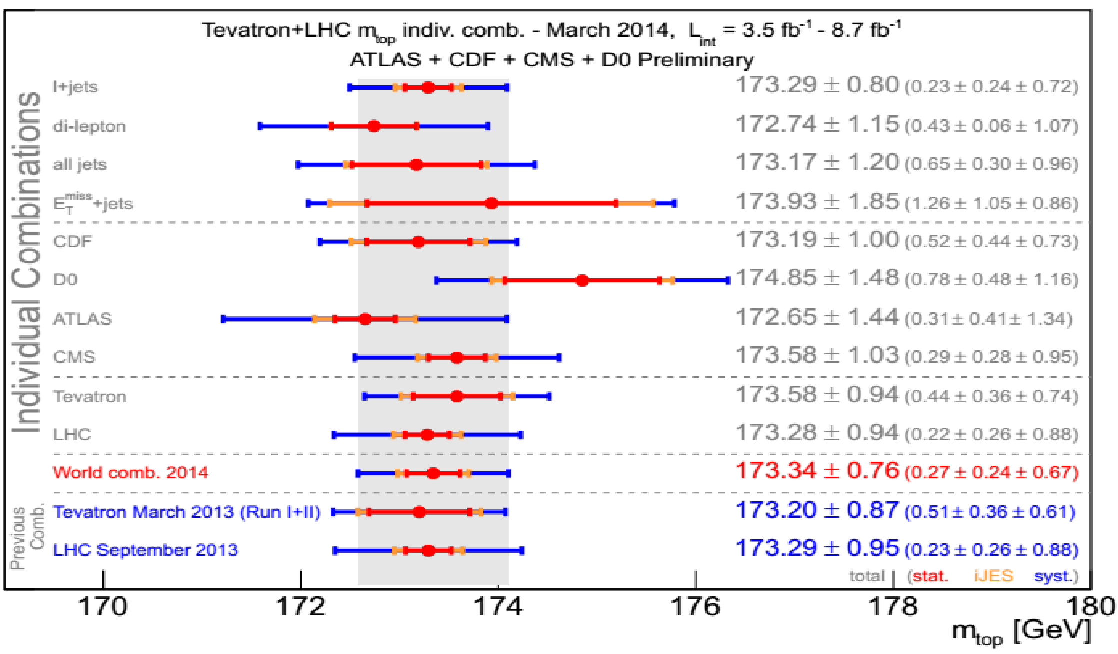

Fig. 7. Input measurements and result of their combination compared with the TEVATRON and LHC combined m_t values [19].

Di-lepton Channel which provides highly precise measurement with 2.3 fb^{-1} of data. (<4.5% uncertainty) for top quark (two W's decay into leptons) at 7TeV and constrained by jet energy scale (JES) [11].

Similarly, mass and cross section measurement for single tops depends on the CKM matrix element V_{tb}. In the t-channel, high transverse momenta top quark is produced

B. Top-quark mass measurement at TEVATRON

TEVATRON is a hadron collider with $p\bar{p}$ collision runs at 1.96 TeV with7.5 fb^{-1}. Most of the top produce in pair at TEVATRON collider detected by CDF and DØ Collaborations. These measurements in the equations (channels) (1) and (2) with $8.7fb^{-1}$ data set have been studied [13, 14]. Similarly to reconstruct mass of Top quark, equations (1) and (2) uses data of 5.6fb^{-1} and 5.8fb^{-1} respectively [15, 16].

In all analyses, template method with event reconstruction uses kinematic fit so that to extract the top mass with very high precision [17, 18].

Template method picks those set of variables x_i sensitive to m_{top} which maximises the liklihood consistent with observation, whereas in matrix element method, Parton Distribution Function (PDF) is calculated on event-by–event basis by using following equation.

$$P_i(\vec{x}_1) = \frac{1}{N}\int TF(\vec{x}_1 \mid \vec{y}_1) d\sigma(\vec{y}_1, m_t) \qquad (5)$$

TF in equation (5) is transfer function that is used by parton level quantities to map them accordingly. The reconstruced m_{top} after liklihood fit calculated by DØ collaboration at 1.96 TeV with 3.6fb^{-1} luminosity is 173.34 ± 0.76 GeV [19].

IV. Conclusion

The précised value of m_{top} will allow experimentalists for verification of further mathematical predictions that will provide the strong connections between the Higgs top and their intermediate particle of electro weak force i.e. W boson. Theorists are currently working to explore its more precise value that will change the predictions regarding Higgs field and its ultimate effect on exploration of universe [18]. It will also provide the framework for searching beyond standard model that will lead for our better understanding of the universe.

In future, BSM constraints derived from top physics measurements will continue to improve until 2035. Top quark studies at future facilities have the potential to deliver the transformation that this field needs to have higher energy hadron colliders so that Yukawa coupling goes to one with 0% control to systematics.

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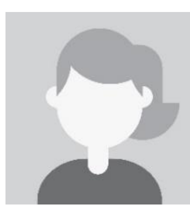

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