Top quark measurement in the CDF

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Abstract. We present recent top physics results in the CDF including updates of top mass, \( t\bar{t} \) cross section, single top search, forward-backward asymmetry, and the differential cross section of \( t\bar{t} \). Most of measurements utilize close to the integrated luminosity of 3 fb\(^{-1}\).

1. Introduction
During the last decade after discovery of top quark \([1, 2]\), top quark has been inclusively studied. By now, the mass of the top quark has been measured to be 172.4\(\pm\)1.2 GeV/c\(^2\) \([3]\) which is the most precisely measured quark mass and \( t\bar{t} \) pair production cross section has been measured as less than 10\% of uncertainties. However, many of another top quark property have not yet been well explored due to the limited statistics. In the ongoing data taking at Fermilab’s Tevatron proton-antiproton collider with Collider Detector at Fermilab (CDF), an increasing of integrated luminosity around 3 fb\(^{-1}\) can make us to measure the property and also discover the unexpected phenomena from top sector. We describes a few of the CDF’s progress of top quark measurement in the following.

2. Top quark measurement
2.1. Top quark production
The predominant production of top quark in the Tevatron is the \( t\bar{t} \) pair production. Measurement of the \( t\bar{t} \) production cross section is important for test of the predictions from perturbative QCD calculations at high transverse momentum at the level of 10\%. Deviation from the Standard Model (SM) predict new physics like resonant production.

CDF have been measured \( t\bar{t} \) cross section in various different decay topology. Fig. 1 shows the results from various different way in the CDF and combination with up to 2.8 fb\(^{-1}\). All of results are consistent with SM prediction. The measured uncertainty in the combination is already reaching the relative uncertainty of the prediction from QCD calculation.

In this combination, one of dominant uncertainty is the luminosity measurement. This effect can be canceled taking the ratio of the \( t\bar{t} \) to the \( Z \) cross section by measuring the \( Z \) cross section because we precisely know the \( Z \) cross section from SM calculation. Then we measure

\[
\sigma_{t\bar{t}} = 6.9 \pm 0.4 \text{ (stat.)} \pm 0.4 \text{ (syst.)} \pm 0.1 \text{ (theory)}
\]

in the lepton jet channel which give smaller uncertainty than the CDF combination using same amount of data.

Since new production mechanism for top quark pairs can make the shape of \( t\bar{t} \) invariant mass as resonances or general shape distortions, the generic method to search the such contribution is to compare the shape of the observed differential \( t\bar{t} \) cross section \( d\sigma/dM_{t\bar{t}} \) with SM expectation.
The mass of the top-antitop system is reconstructed for each event by combining the four vectors of the four leading jets, lepton, and missing transverse energy. The unfolding technique implemented to correct the reconstructed distribution as for direct comparison with theoretical differential cross section. In the update with 2.7 fb$^{-1}$ data, we have in-situ jet energy scale (JES) measurement using di-jet mass of $W$ boson decay, which have been used in the top quark mass measurement, that we can significantly reduce the JES systematics. As one can see in Fig. 2, we do not find any significant difference with SM expectation. We check the consistency using the Anderson-Darling (AD) statistics [6]. We calculate a p-value of 0.28 using AD statistics which have a good agreement with the SM [7].

Figure 1. The CDF combination of $t\bar{t}$ cross section measurement using up to 2.8 fb$^{-1}$ is shown.

There are several searches of single top production using a variety of multivariable techniques such as neural network, boosted decision trees, likelihood function, and matrix element in the decay topology with having one charge lepton (electron and muon), missing transverse energy and jets (at least one $b$-jet). Each of measurement builds a discriminant to separate signals from backgrounds using multivariables. We can extract the signal from the distribution of the discriminant. At the end, four different discriminants can be an input of super discriminant using neuro-evolution network. Using 2.2 fb$^{-1}$ of data, we measure the single top cross section as,

$$\sigma_{st} = 2.2^{+0.7}_{-0.6} \text{ pb}$$
We have one analysis in the orthogonal decay topology which contain missing transverse energy and jets (at least one $b$-jet), in order to pick up signal events which do not reconstruct electron or muon, or contain hardronic decay tau. We build a discriminant using a neural network technique which we can extract signal top cross section as,

$$\sigma_{st} = 4.9 \pm 2.5 \text{ pb}$$

using 2.1 fb$^{-1}$ dataset [9].

2.2. Top quark mass measurement

The top mass is a fundamental parameter of the SM since it is a dominant parameter in higher order radiative corrections to other SM observables. The accurate determination of the top mass, combined with precision electroweak measurement, constrains the mass of the SM Higgs boson.

The best precision of top quark mass by single measurement [10] is based on matrix element calculation of process using lepton jets channel which we measure the top quark mass at the precision of less than 1% level. The combined top quark mass with 2.7 fb$^{-1}$ dataset is

$$M_{\text{top}} = 172.4 \pm 1.0 \text{ (stat.)} \pm 1.3 \text{ (syst.)}$$

with 3.0 fb$^{-1}$ dataset [13]. This measurement is the first application of the $m_{T2}$ variable in the real data. The methods used in this measurement will be applicable to other measurement of new physics particles search at the Tevatron and LHC.

2.3. Forward-Backward Asymmetry in Top Production

The forward-backward asymmetry in top production has been measured at CDF. In the next-to-leading order (NLO) calculation, a small charge asymmetry, which is corresponding to a forward-backward asymmetry ($A_{FB}$), is calculated to be $A_{FB} = (5.0 \pm 1.5)\%$ in $q\bar{q} \rightarrow \text{t}\bar{t}$. Because top quark production in the LHC is dominated by gluon fusion, the Tevatron is a unique place to measure this effect. CDF have two different measurements in the different rest frame: $p\bar{p}$ (Fig. 3) and $\text{t}\bar{t}$ (Fig. 4). The measured results with 1.9 fb$^{-1}$ of CDF data are $A_{FB}^{p\bar{p}} (\text{meas}) = 0.17 \pm 0.07 \text{ (stat.)} \pm 0.04 \text{ (syst.)}$ and $A_{FB}^{\text{t}\bar{t}} (\text{meas}) = 0.24 \pm 0.13 \text{ (stat.)} \pm 0.04 \text{ (syst.)}$. This measurements are a bit higher than the SM NLO prediction but, still it is consistent [14] with SM.

3. Conclusions

Number of top quark properties not only mass and production cross section but numerous studies for top properties have been measured. However many measurements are still limited by the statistical uncertainty. Although we do not find evidence conflicting with SM top quark, we expect to have interesting measurement with more data in near future.
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