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IS THERE ONLY TOP QUARK? - REVIEW OF TOP RESULTS

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The CDF published top results on counting experiments, cross section measurements(with D0 results also), mass measurements, and kinematics are reviewed. Overall speaking, all the measured top properties are consistent with SM top hypothesis within the measurement uncertainties using present $110pb^{-1}$ of data. Some aspects of the peculiarities of the top samples are discussed and quantified. There are some event excesses in top counting experiment results. But they are not statistically significant enough due to the limited data size. All the CDF top measured cross section values are found to be consistent with the theoretical calculations within the measurement uncertainties but with higher central values. Some of the peculiar aspects of mass samples and kinematic distribution results are also discussed.

1 Motivation

Top was observed[1,2] at Fermilab in 1995 with exceptional large mass of 176 GeV. Because of its unnatural large mass, some theorists proposed to look for either new physics beyond Standard Model(SM)[3] or information on Planck-scale physics[4]. Recently, there were some interests generated by looking at some peculiar aspects of top samples at the top-quark physics thinkshop[5] for Run II which was held at Fermilab between October 16 and 18, 1998. The focuses of peculiar aspects were on the larger overall counting rates in dilepton sample[6], mass measurements of all samples, and the kinematic distributions of lepton+jet data sample[7].

In the following sections, I will examine part of the published and blessed top results purely from experimental point of view and report what was found without any theoretical speculations or assumptions.

2 Introduction

Since the top discovery, lots of efforts have been undertaken into studying top properties like production cross sections[10], mass[12], kinematics[13], hadronic W decays in t-tbar events[14] ... etc. Overall speaking, all the measured top properties are consistent with SM top hypothesis within the measurement uncertainties using present $110pb^{-1}$ of data. No obvious deviation from SM top hypothesis was observed.

In the published results[10], the value of top cross section was extracted within the assumption of SM. This value was then used to evaluate the number of expected top events in each jet multiplicity for comparing the total expected and observed events. This is a self-consistent check assuming SM. If SM were the only and valid picture for top measurements, we would expect every pieces should fall into places in one picture. Within the measurement uncertainties, all the measured top cross sections are found to be consistent with theoretical values.

However, if one looks closer, there appears a trend that all the measured top cross section central values are systematically larger than the values predicted by SM. Accordingly, one also finds some small excesses in counting experiment results. Beside these, there are some deviations in the kinematic distributions of the t-t(bar) system. All these detailed aspects seem to suggest that there might be some clues for a small fraction of abnormal events which accompany the top in some or all top samples.

In order to address the significances of these peculiar aspects, we would include number of expected top events which was estimated from theoretical calculations into the overall number of expected event and then estimate the significance of each excess. Since the top cross section is a function of top mass, the uncertainties of the estimated number of top events due to the uncertainties of top mass measurements should be taken into account. However, this part of uncertainti(about 10%) was not included in the following significance calculation. The results obtained from top data samples in counting experiment, cross section, mass measurements, and kinematics will be reviewed and quantified if possible in the following sections.

3 Top Counting Measurements at CDF

According to SM, top quarks are produced in pair and instantaneously decay into W and b particles. Therefore, top event topology is characterized by 3 different combinations of W decay products when: (I) both W's decay leptonically, it is called dilepton sample. (II) one of the W's decay leptonically and the other one decay hadronically, it is called the lepton+jets sample. (III) both W's decay hadronically, it is called all-hadronic sample. The third case will not be discussed in this article. For both the dilepton and lepton+jets channels, the event selection of a primary lepton are the same.

An observed event excess in counting experiment is the most direct way to reveal the possibility of the existence of peculiar events. A new sources of processes could merge as excess events if all SM processes in each sample are understood and included correctly in the estimation of the expected number

Table 1: List of top dilepton candidate events for all channels.

Channel	Dilepton Candidates	Other SM Processes	Top[M =175 GeV,σ=5.5 (4.75) pb with 15(18)% error]	SM Processes + Top
$e\mu$	7	0.8 $\pm$0.2	2.7$\pm$0.4(2.3$\pm$0.4)	3.5$\pm$0.4(3.1$\pm$0.4)
$ee+\mu\mu$	2	1.6 $\pm$0.5	1.7$\pm$0.3(1.5$\pm$0.3)	3.3$\pm$0.6(3.1$\pm$0.6)
all	9	2.4 $\pm$0.5	4.4$\pm$0.7(3.8$\pm$0.7)	6.8$\pm$0.9(6.2$\pm$0.9)

of events.

There are couple excesses observed in the CDF counting results. Both results of dilepton and lepton+jet channels are presented here. We will quantify all the excesses in terms of an upward fluctuation probability assuming SM processes as the null hypothesis. Ten thousand pseudo experiments for each test were carried out using Poisson distribution convoluted with Gaussian distribution for the expected number of events and its corresponding uncertainty.

3.1 Dilepton Sample

The following observations and summaries are based on top dilepton PRL(1998) [15]. In the dilepton with 0 jet bin, there are 8 observed events with expected top and SM background of 8$\pm$ 2 events[15]. These 8 events are dilepton events which pass all selection cuts but they have no jet. The number of observed and the expected events agree exactly. In the dilepton with 1 jet bin, there are 11 observed events and 7$\pm$ 2 events[15] of expected top and SM backgrounds. These 11 events are dilepton events which pass all selection cuts but they have only one jet. The upward fluctuation probability for 11 or more observed events with expected events of 7$\pm$ 2 was found to be 14%. In the dilepton with 2 or more jets bin, there are 9 observed top dilepton candidate events with SM background estimation[15] of 2.4$\pm$0.5. If we assume the theoretical top production cross section as $5.5 \pm 0.8(4.75^{+0.73}_{-0.62})$ pb[9,8], we expect $4.4 \pm 0.7(3.8 \pm 0.7)$ of top dilepton events with absolute dilepton acceptance[15] of (0.74 ± 0.08)% for a top mass of 175 GeV. In total, we expect $6.8 \pm 0.9(6.2 \pm 0.9)$ top+SM background events. The upward fluctuation probability for 9 or more events was found to be 25% (18%).

Further, if one looks into different categories of dilepton candidate events, one would find the $e\mu$ events have a more significant excess than others. The break down of observed, background, and expected top events are listed in table 1. The upward fluctuation probability for 7 or more $e\mu$ events with expected events of 3.5$\pm$0.4(3.1$\pm$0.4) was found to be 7%(4%).

Four of the nine candidate events have one jet tagged as a b jet by the presence of secondary vertex in the silicon vertex detector (SVX tag). Two of these four jets are also tagged by a soft lepton from the semileptonic decay of the b quark(SLT tag). In a sample of 4.4 expected top events, 2.7 ± 0.25 jets are expected to be tagged by at least one of the two tagging algorithms. The upward fluctuation probability for 4 or more jets with expected jets of 2.7 ± 0.25 was calculated to be 29%.

In summary, there are excesses in opposite-sign dilepton events with 1 jet and with 2 or more jets. There is also excess in the number of b-tagged jet of the dilepton events with 2 or more jets. Among all these excesses, the one in $e\mu$ channel of dilepton events with 2 or more jets is the most significant excess with an upward fluctuation probability of 7%(4%).

3.2 Lepton+jet Sample

In this sample, the key point of identifying top quarks and reducing background is to search for energetic b quark from top decay. Two approaches were used to look for these energetic b quarks in top analysis. The more powerful SVX method in which high precision track information obtained from Silicon VerteX detector (SVX) was used to reconstruct displaced secondary vertex with respect to the primary vertex(interaction point). With values of displaced secondary vertex decay length, we could select SVX b-tagged events from this lepton+jet sample. The other method is called the Soft Lepton Tag (SLT) in which soft leptons from b semileptonic decays within b jets with averaged Pt of 10 GeV/C were identified. With the existence of soft lepton candidate, we could select SLT b-tagged events from this lepton+jet sample.

SVX Single-Tagged Events

The following observations and summaries are based on PRL(1998) [10]. In the lepton+1 jet bin, there are 70 observed events with expected top and SM background of $71.7\pm$ 11 events[10] assuming top cross section of 5.5 pb[9]. The number of observed and the expected events agree very well. In the lepton+2 jet bin, there are 45 events and with expected top and SM background of $36\pm$ 4.3 events[10]. The upward fluctuation probability for 45 or more observed events with expected events of $36\pm$ 4.3 is 12%. In the lepton+3 jet bin, there are 18 observed events with expected top and SM background of $16.8\pm$ 2.8 events[10] assuming top cross section of 5.5 pb[9]. The number of observed and the expected events agree very well. In the lepton+$\geq$4 jet bin, there are 16 observed events with expected top and SM background of $14.8\pm$ 3.4 events[10] assuming top cross section of 5.5 pb[9]. The number of observed and the expected events agree very well.

Table 2: Summary of doubled-SVX-tagged events.

	W+1 jet	W+2 jets	W+3 jets	W+$\geq$ 4 jets
QCD	0	1.6±0.4	0.3±0.1	0.15±0.03
top(7.5pb)	0	1.4±0.4	3.3±0.5	5.0±1.1
top(5.5pb)	0	1.0±0.3	2.4±0.4	3.7±0.8
top(5.5pb)+QCD	0	2.6±0.5	2.7±0.4	3.9±0.8
observed(e+jets)	0	2	3	2
observed(μ+jets)	0	4	3	0
observed total	0	6	6	2

In summary, the agreements between number of observed and expected events in lepton+1 jet, lepton+3 jet, and lepton+$\geq$4 jet bins are very well. Since in the lepton+$\geq$4 jet bin, there is no obvious excess, we would expect that the mass distribution of this sample is well fitted by the combined simulated mass distributions of SM processes and top. However, there is an excess in the lepton+2 jet bin with an upward fluctuation probability of 12%.

3.3 Lepton+jet SVX/SLT Doubled-Tagged Events

The information of doubled-tagged events are quoted from the Search for New Particles PRL[16]. Among these events, one jet was required to be tagged by SVX and the other jet was required to be tagged by either SVX or SLT. The observed doubled-tagged and estimated background events are listed in table 2

There is no observed and expected doubled-tagged events in the W+1jet bin. In the lepton+2 jet bin, there are 6 events with expected top and SM background of 2.6±0.5 events[16]. The upward fluctuation probability for 6 or more observed events with expected events of 2.6±0.5 is 6%. In the lepton+3 jet bin, there are 6 observed events with expected top and SM background of 2.7± 0.4 events[16] assuming top cross section of 5.5 pb. The upward fluctuation probability for 6 or more observed events with expected events of 2.7±0.4 is 6%. In the lepton+$\geq$4 jet bin, there are 2 observed events with expected top and SM background of 3.9± 0.8 events[16] assuming top cross section of 5.5 pb. The number of observed and the expected events are consistent with each other with downward fluctuation probability of 28%.

If one assume the two 6% excesses(doubled-tagged) in the W+2 and W+3 jets bins are independent to each other, the combined $\alpha^{'}$ is given as a value of 11.3 by the formula[17] listed below:

$$\alpha^{'} = -2 * ln * \prod_{i=1}^{N} \alpha_i \qquad (1)$$

Table 3: List of top cross section measurements for all channels.

Channel	CDF measurements(pb)	D0 measurements(pb)
Dilepton	$8.2^{+4.4}_{-3.4}$	6.4 ± 3.3
Lepton+Jet(SVX)	$6.2^{+2.1}_{-1.7}$	N/A
Lepton+Jet(SLT)	$9.2^{+4.3}_{-3.6}$	8.3 ± 3.5
Lepton+Jet(topology)	N/A	4.1 ± 2.1
Hadronic	$10.1^{+4.5}_{-3.6}$	7.1 ± 3.2
Combined	$7.6^{+1.8}_{-1.5}$	$5.9^{+1.7}_{-1.7}$
Theoretical	4.7−5.5	

which is distributed(under null hypothesis) as a χ^2(2*N). Therefore, the combined significance or upward fluctuation probability was calculated to be 2%.

4 CDF and D0 Top Cross Section Measurements

The second aspect is based on the CDF and D0 top cross section measurements[11]. All the cross section results are listed in table 3. For each individual cross section measurement, the measured value is consistent with theoretical calculations within one sigma. So the agreement is very well. However, one notices that all CDF cross section measurements are higher than the theoretical calculations and only one D0 measurement is below the theoretical calculations. For the combined cross section measurements, the CDF result is higher than the theoretical calculation for more than a sigma and the D0 result is consistent with theoretical calculation within one sigma. In summary, there is only 1 measurement falling below 4.7 pb and the rest of 7 measurements are all above 5.5 pb.

I then used the sign test[18] which is based on the binomial distribution to test the consistency between the concatenated CDF/D0 measurements and the theoretical prediction. With one-sided sign test, this configuration of 8 measurements is not consistent with the theoretical prediction at 3.5% level.

5 CDF Top Mass Measurements

In CDF blessed results, all mass measurements methods adopted are based on an assumption that each event in the selected data sample contains a pair of top and anti-top quarks with equal mass. They then decay according to SM description. Mass measurements of the dilepton, lepton+jets, and all−hadronic samples are listed below[7]:

Table 4: Reconstructed top mass of each subsample.

Subsample	Reconstructed top mass
SVX double tag	170.1±9.3
SVX single tag	178.0±7.9
SLT tag	142^{+33}_{-14}
No tag($E_T(j_4) \geq 15$ GeV)	181.0±9.0

a. dilepton(with 2 jets):
   Neutrino-weighting method
   167.4 ± 10.7 ± 4.8 GeV/C^2
   "MINUIT" fitting method
   170.7 ± 10.6 ± 4.6 GeV/C^2
   Dalitz-Goldstein method
   157.1 ± 10.9 ± 4.4 GeV/C^2

b. lepton+jets(with 4 jets):
   175.9 ± 4.8 ± 5.3 GeV/C^2

c. all hadronic mode(with 6 jets):
   186.0 ± 10.0 ± 5.7 GeV/C^2

Within the measurement uncertainties, every measurement is consistent with each other. However, if one looks more closer, there is a trend that an increase of the reconstructed mass value corresponds to the increasing number of jets in an event.

If one looks into the mass results in the lepton+jet subsamples, one may find another peculiar aspect. In figure 1, one sees that the SLT tagged sample seems to have more background events than what was expected from background calculation. This measured top mass of SLT sample is even as low as 142 GeV/c^2. The individual reconstructed mass values of each sample is listed in table 4.

6 CDF Top Kinematics

Overall speaking, most of the kinematic distributions are consistent with the hypothesis of SM top and QCD backgrounds. There are two kinematic distributions of the t-tbar system which show some deviations from expectation. The first one is the Pt(transverse momentum) distribution of the t-tbar system for a sample of 32 SVX-tagged events. This distribution was obtained using the standard CDF mass fitter on the lepton+jets sample. This Pt distribution as shown in figure 2 for the SVX-tagged events is harder than the expected distribution(with dash line) of top and background MC events which were used in the procedure of mass fitting.

The other one is the pseudorapidity distribution of the t-tbar system for the 32 lepton+jet tagged events. This distribution as shown in figure 3 has a different shape than the expected distribution of MC events. If this deviation were not due to a statistical fluctuation, it would be possible to suggest that the hypothesis adopted in the mass fitting procedure for top event topology is not correctly assumed.

7 Summary and Outlook

In summary, all the measured top properties are consistent with SM top hypothesis within the measurement uncertainties using present $110pb^{-1}$ of data. However, there are some excesses observed in top counting measurements and some deviations observed in top cross sections, top mass fitting variables, and kinematic distributions. But these excesses and deviations are not statistically significant enough to suggest evidence of peculiar events beyond the SM hypothesis.

Nevertheless, this survey provides us some clues and motivations to study top properties in a more elaborated way with more data at hand in runII. With anticipated 20 times more data at runII era of Fermilab, we are looking forward to studying the top properties in more details and exploring the possibility of new phenomena beyond SM if one of these peculiar aspects turns out to be not purely statistical fluctuations of known SM processes.

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References

1. F.Abe et. al., Phys. Rev. Lett. 74, 2626 (1995).
   "Observation of top quark production in pp(bar) collisions with the collider detector at Fermilab"
2. S.Abachi et. al., Phys. Rev. Lett. 74, 2632 (1995).
   "Observation of the top quark"
3. C. Quigg, FERMILAB-CONF-95/139-T, (1995).
   "Topology"
4. S. Willenbrock, hep-ph/9611240,05-Nov-96, (1996).
   "Top Quark Theory"
5. http://lutece.fnal.gov/thinkshop/.
   "Thinkshop - Top Quark Physics for RunII"
6. H. Frisch, talk presented at Top Quark Physics for RunII Thinkshop, Fermilab, October 16-18, 1998.
   "Anomalies in the Dilepton Sample"
7. K. Sliwa, talk presented at Top Quark Physics for RunII Thinkshop, Fermilab, October 16-18, 1998.
   "Top Search and Top Mass measurements in CDF - Is Everything Consistent?"
8. Catini, Mangano, Nason and Trentadue, "The top cross section in hadronic collisions", hep-ph/9602208
9. E.Berger and H.Contopanagos, PRD54, 3085 (1996).
   "Perturbative resummed series for top quark production in hadron reactions"
10. F.Abe et. al., Phys. Rev. Lett. 80, 2773 (1998).
    "Measurement of the tt(bar) production Cross Section in pp(bar) Collisions"
11. P.C.Bhat,H.B.Prosper,S.S. Snyder, Fermilab-Pub-98/236(1998).
    "Top quark physics at the Tevatron"
12. F.Abe et. al., Phys. Rev. Lett. 82, 271 (1999).
    "Measurement of the Top Quark Mass with the Collider Detector at Fermilab"
13. F.Abe et. al., Phys. Rev. D59, 92001 (1999).
    "Kinematics of tt(bar) events at CDF"
14. F.Abe et. al., Phys. Rev. Lett. 80, 5720 (1998).
    "Observation of Hadronic W Decays in t-tbar Events with the Collider Detector at Fermilab"
15. F.Abe et. al., Phys. Rev. Lett. 80, 2779 (1998).
    "Studies of the Dilepton decay Channel from tt(bar) Production at the

Collider detector at Fermilab ”
16. F.Abe et. al., Phys. Rev. Lett. 79, 3819 (1997).
“Search for New Particles Decaying into bb(bar) and Produced in Associated with W Bosons Decaying into e-nu or mu-nu at the Fermilab Tevatron.”
17. W.T. Eadie et. al. , p.282-283, (1971).
“Statistical Methods in Experimental Physics”
18. A.G. Frodesen, O. Skjeggestad, p.436-438, (1979).
“Probability and Statistics in Particle Physics”

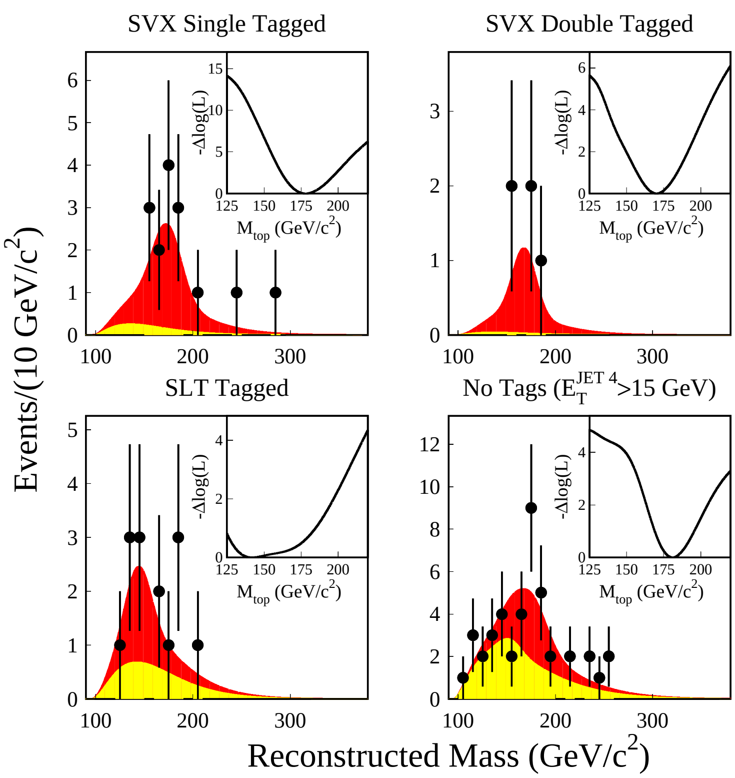

Figure 1: Reconstructed mass plot of each sample.

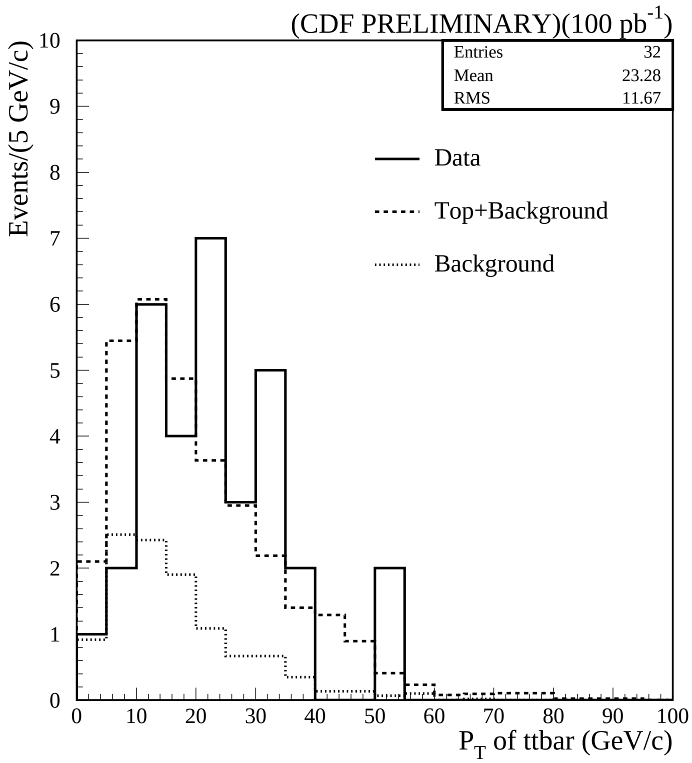

Figure 2: Pt of t-tbar system.

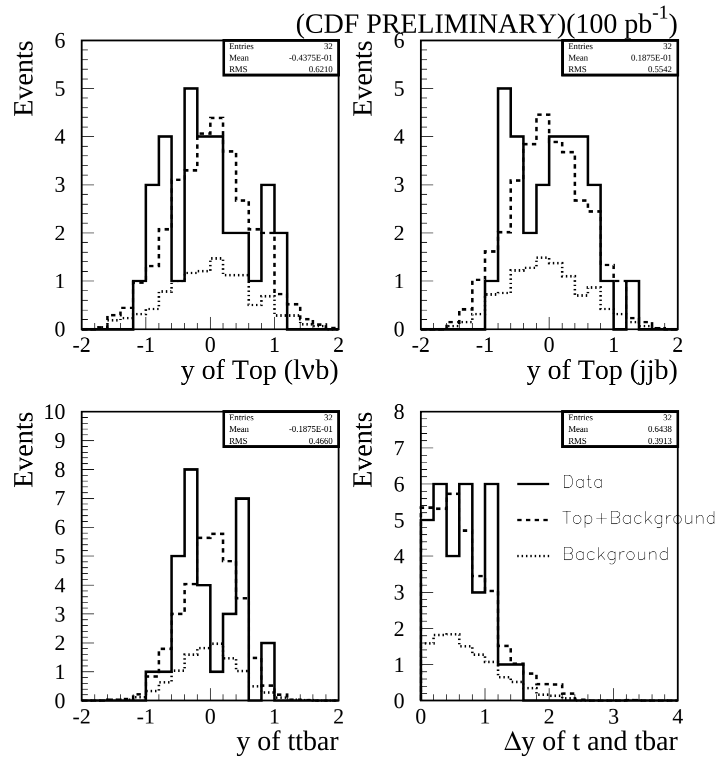

Figure 3: Pseudorapidity of t-tbar system.