Measurement of $t\bar{t}$ Production Cross Section at CDF II Using b-Tagging

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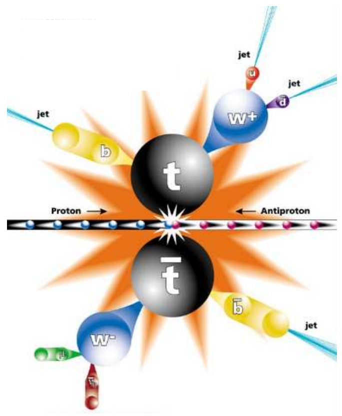
ABSTRACT

The CDF detector has been upgraded for the Tevatron Run II, which started in December 2001 at a new center-of-mass energy of 1.96 TeV. We present here a preliminary result of the $t\bar{t}$ production cross-section using b-tagging in the lepton+jets decay channel.

Top Quark Production at Tevatron

The Top quark was discovered at the Tevatron in 1995. It is by far the heaviest quark: with a mass of the order of the electroweak scale (175 GeV), it offers a great opportunity to test the Standard Model.

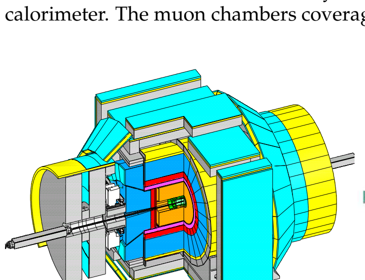
At the Tevatron, $t\bar{t}$ pairs are produced through quark annihilation (85%) and gluon fusion (15%). In the Standard Model, Top quarks decay almost exclusively to a W boson and a Bottom quark. In turn, the W bosons can decay either leptonically or hadronically. Hence 3 distinct channels are observable: the "di-lepton" channel (both W's decay leptonically) is very clean but has a small branching ratio (5%); the "lepton+jets" channel (one W decays leptonically, the other one decays hadronically) has more background but a larger branching ratio (30%); the "hadronic" channel (both W's decay hadronically) has the largest branching ratio (44%) but the important background from QCD processes makes it a difficult channel to study.

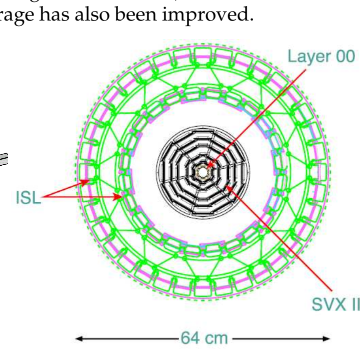


The analysis presented here uses the lepton+jets channel, allowing the lepton to be either a muon or an electron.

The CDF II Upgrade

The CDF detector has gone through a major upgrade for Run II. The most relevant upgrades for this analysis are a completely new tracking system (an 8 layer silicon vertex detector surrounded by a large drift chamber), and a new forward calorimeter. The muon chambers coverage has also been improved.





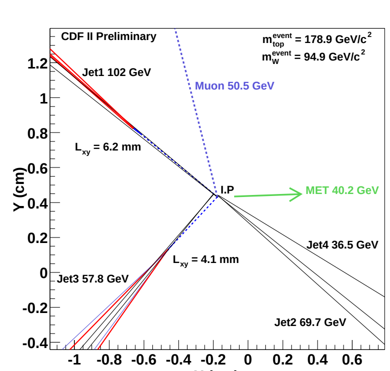
The new silicon detector, about twice longer than the previous one, increases the acceptance of b-tagged $t\bar{t}$ events by about 30%.

Event Selection and Data Sample

We select $t\bar{t}$ events in which one W decays to an electron or a muon, and the other W decays to two quarks. The signature is the following:

- Single high-p_T lepton ($p_T > 20$ GeV)
- 3 or more jets ($p_T > 15$ GeV)
- Large missing E_T (> 20 GeV)
- In order to enhance the signal over background ratio, we additionally require at least one jet to be identified as a b-jet.

This is a 2D vertex display of a typical Top event at CDF. Two out of the four jets are identified as b-jets. The red tracks indicate tracks that are part of the displaced secondary vertex.

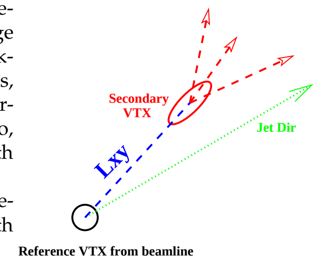


The data used for this analysis were taken between March 2002 and January 2003, and amounts to an integrated luminosity of 57 pb^{-1}.

b-Jet Identification

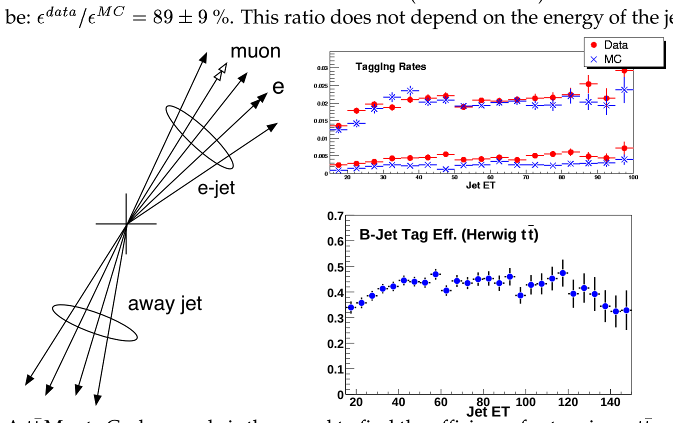
Algorithm

Secondary vertices are reconstructed by selecting tracks within the jet that have a large impact parameter and satisfy some tracking quality requirements. In a first pass, the algorithm attempts to reconstruct vertices with at least 3 tracks. If it fails to do so, it tries to reconstruct 2 track vertices with more stringent cuts on the track selection. A jet is "tagged" if a secondary vertex is reconstructed with a significant decay length in the transverse plane (L_{xy}).



Efficiency Measurement

Understanding the algorithm efficiency is a crucial part of this analysis. The efficiency is measured separately in the data and in the Monte Carlo, in a heavy flavor enriched sample. In the data, the heavy flavor content of the sample is measured by identifying charm mesons from the decay: $D^0 \rightarrow K^{\pm}\Pi^{\mp}$. The ratio of efficiencies in data and Monte Carlo ("scale factor") was measured to be: $\epsilon^{data}/\epsilon^{MC} = 89 \pm 9\,\%$. This ratio does not depend on the energy of the jet.

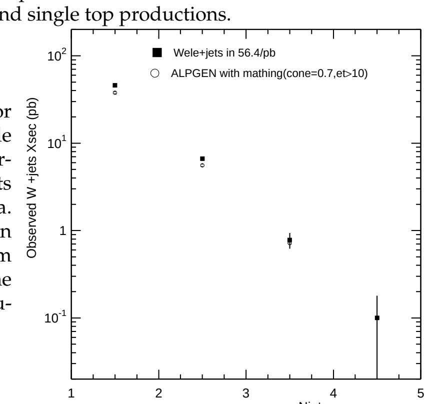


A $t\bar{t}$ Monte Carlo sample is then used to find the efficiency for tagging a $t\bar{t}$ event (taking into account the scale factor). We find that the efficiency to tag at least one jet in a $t\bar{t}$ event (satisfying all kinematic criteria) is: $\epsilon_{t\bar{t}} = 45 \pm 1 \pm 5\,\%$. An event-by-event primary vertex finding algorithm allows to reach an efficiency of 55%, but was not used in the analysis presented here.

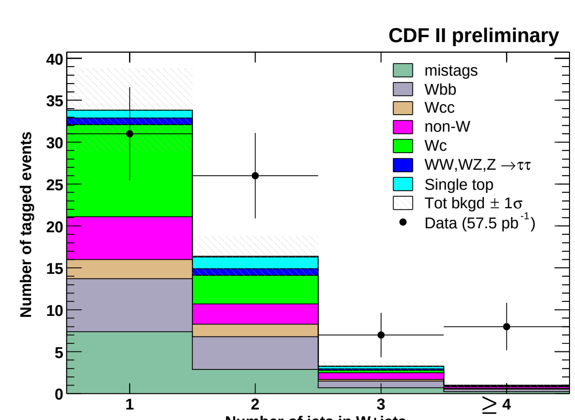
Composition of the W + jets Sample

The dominant backgrounds to the $t\bar{t}$ signal in the b-tagged W+jets sample include contributions from heavy flavor physics events ($Wb\bar{b}$ and $Wc\bar{c}$), fake b-tags ($Wq\bar{q}$), and fake isolated leptons in QCD events. A smaller contribution comes from Z+jets, di-boson and single top productions.

We evaluate the heavy flavor fraction of the W+jets sample from Monte Carlo. The normalization of the overall W+jets cross-section is taken from data. This plot shows the prediction of the W+jets cross-section from ALPGEN, which describes the data with a reasonable accuracy.



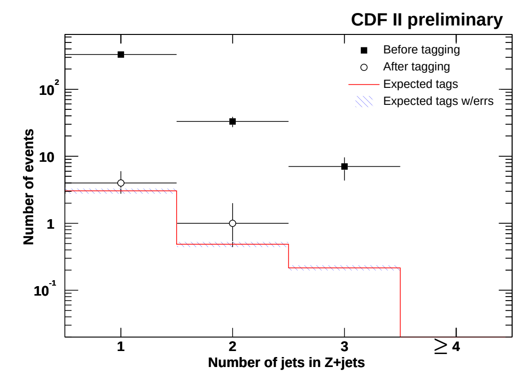
Backgrounds are estimated as a function of jet multiplicity. The background estimates in the 1-jet and 2-jet bins are a good check of the method because the $t\bar{t}$ signal contribution in these bins is quite small. The plot below shows the sum of all background contributions, compared to the data. An excess in the 3 and ≥4 jets bins, attributed to $t\bar{t}$ events, is clearly visible.



Jet Multiplicity	1 jet	2 jets	≥3 jets
Background	33.8±5.0	16.4±2.4	3.8±0.5
Data	31	26	15

The Z + jets Sample

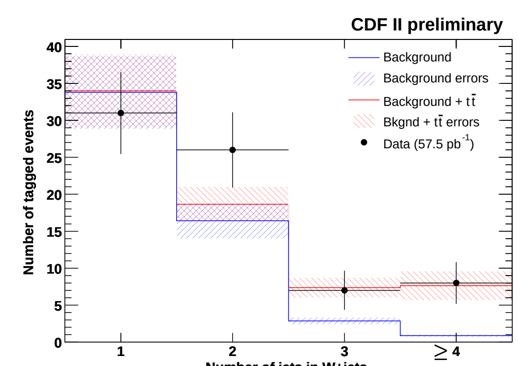
The Z+jets sample is used as a cross-check of our understanding of the heavy-flavor content. The following plot shows the jet multiplicity of Z+jets events, tagged Z+jets events, and expected number of tagged Z+jets events (the tag rate is assumed to be the same as in an inclusive jet sample, and normalized to the whole Z+jets sample).



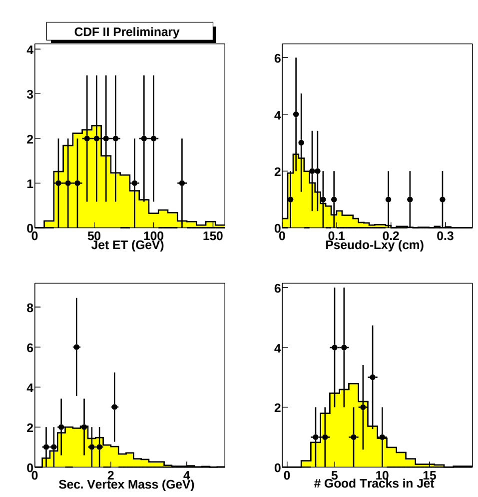
Cross Section Calculation

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkd}}{\epsilon_{t\bar{t}}\mathcal{L}} = 5.3 \pm 1.9(stat.) \pm 0.8(syst.)\ \text{pb}$$

The following plot shows the jet multiplicity of the expected background, with and without the $t\bar{t}$ contribution, compared to the data. The $t\bar{t}$ contribution is normalized with the measured cross-section, while Monte Carlo is used to estimate the shape. The 1-jet and 2-jet bins are in good agreement with the prediction. A small excess is visible in the 2-jet bin, but the low statistics do not allow to draw any conclusion.



Some characteristics of the tagged jets of our 15 candidates, compared to $t\bar{t}$ Monte Carlo:



The CDF measurements of the $t\bar{t}$ cross-section at a center-of-mass energy of 1.8 TeV (Run I) and 1.96 TeV (Run II) are in good agreement with the theoretical Standard Model predictions.