DØ TOP PHYSICS

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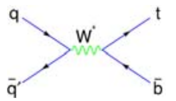
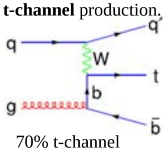
Single Top Quark Production

According to the Standard Model, along with pair production, single top quarks can be produced via the exchange of a W-boson. Dominant modes of single top production at the Tevatron are **s-channel** and **t-channel** production.



30% s-channel



70% t-channel

The theoretically expected **production rate** (cross-section) at the Tevatron's center of mass energy of 1.96 TeV is **2.9 picobarns** (1 pb = 10^{-12} barn = 10^{-36} cm^2).

s-channel theoretical cross section =0.88 pb

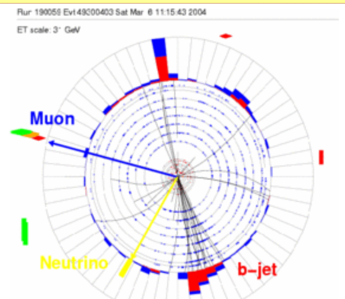
t-channel theoretical cross section =1.98 pb

By observing the interaction vertex between a W-boson, a top quark and a bottom quark at production, we can measure directly -and for the first time- the strength of the coupling between these particles: the so-called **V_{tb} element** of the Cabibbo-Kowayashi-Maskawa (CKM) mixing matrix. So far only indirect constraints exist on this parameter.

The interest of this process goes beyond the Standard Model:

- **New heavy particles** could enhance the production cross section in the s-channel,
- **Anomalous couplings** (like those predicted from a 4^{th} family of quarks or other exotic theories) would enhance the t-channel production.

Thus, top quarks offer a vantage point to study new phenomena beyond the Standard Model given their high mass and their preferred coupling to the Higgs boson that is thought to give mass to all particles.



Candidate event

Search for Single Top Quarks

Selection cuts & b-tagging

Selection

The final state, concentrating only on semileptonic top decays (t→bW→blν).

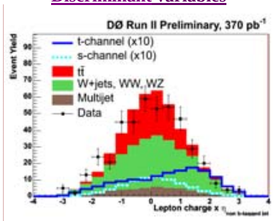
Events are selected loosely, trying to keep a high acceptance since this is a search, with a basic set of cuts: One electron or muon with p_T>15 GeV, Missing Energy >15 GeV, and 2, 3 or 4 jets each with energy >15 GeV, the leading jet with energy >25 GeV.

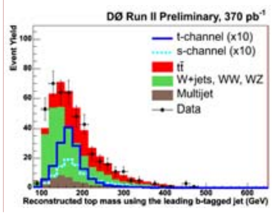
We apply the **Jet Lifetime Probability** (JLIP) algorithm to identify a b-jet with **~50% efficiency** and **~99.6% purity**.

The selection is loose intentionally so that advanced multivariate techniques can exploit the kinematic differences between the single top signal and backgrounds.

We form a discriminant for each s- and t-channel signal, for the two major backgrounds (W+jets and tt), for one and more than one b-tags and for each lepton flavor (e and μ).

Discriminant variables

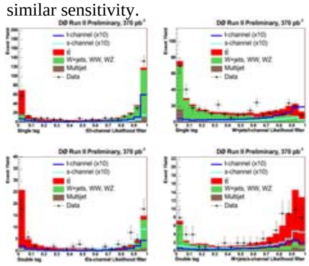




Multivariate analyses

Neural Network and a **likelihood discriminant** are examples of multivariate techniques which incorporate the shapes of mostly uncorrelated input variables to distinguish between signal and backgrounds.

Neural networks and likelihoods have similar sensitivity.



Limit setting

Instead of cutting on the output of the discriminant to count the expected number of single top events versus the backgrounds, we build a binned likelihood function based on the Poisson probability to observe the number of events in each bin of each distribution.

A Bayesian analysis returns a posterior probability density function which can be used to calculate the limit.

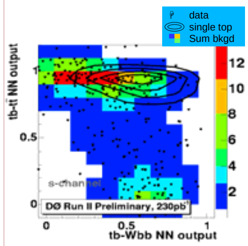
Likelihood discriminant results with **370pb⁻¹** of data, 95% CL upper limits:

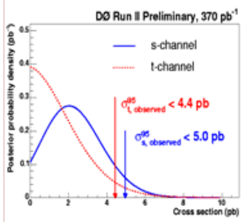
s-channel cross section < 5.0 pb

t-channel cross section < 4.4 pb

expected 95% CL upper cross section limits [pb]

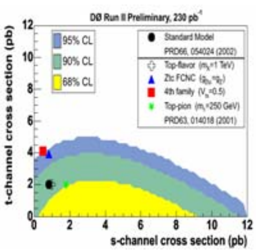
	s	t
D0 Likelihood (370 pb⁻¹)	3.3	4.3
CDF NN (700 pb⁻¹)	3.7	4.2





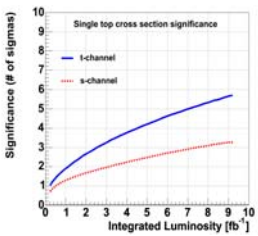
Projected Sensitivity and Future Improvements

We are very close to observing single top and ruling out many new physics models



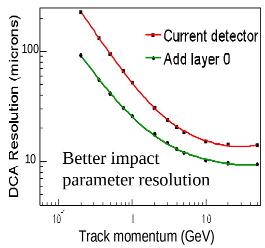
← Exclusion on the plane of s- and t-channel cross sections. The colored points represent models of physics beyond the Standard Model

→ Given the current DØ analysis, we would need a few fb⁻¹ for an observation. But of course we are going to improve the analysis, so expect an observation sooner!



Present analysis is just a beginning.
We are very close to having **1000pb⁻¹** of data analyzed with more sophisticated analysis techniques, improved b-tagging and better jet energy scale.

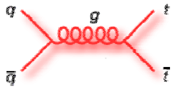
With addition of Layer 0 in our silicon tracker, with better IP resolution, b-tagging will get even better. Other upgrades will also make our detector more efficient in higher luminosity environment, improving our physics output.



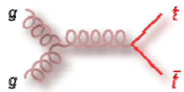
With L0, relative increase of b-tagging efficiency is 15%

Top Quark Pair Production and Decay

According to the Standard Model, at the Tevatron top quarks are predominantly **generated in pairs** via the strong interaction by quark-antiquark annihilation, that is, the top quark (t) is most often produced together with its antiparticle, the antitop quark ($\bar{t}$):



85% $q\bar{q}$ annihilation



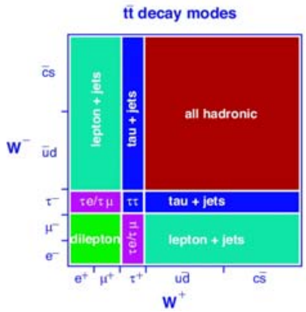
15% gg fusion

The theoretically expected **production rate** (cross-section) at the Tevatron's center of mass energy of 1.96 TeV is **6.77 ± 0.42 picobarns** [PRD 68, 114014 (2003)] (1 barn (b) = 10^{-28} m^2, 1 pb = 10^{-12} b).

In the Standard Model both the top quark and the antitop quark decay almost always into a b-quark and a W boson (carrier of the weak force). The final **signature of the top quark pair decay** depends on the **decay mode of** the two produced **W bosons**. The possibilities are:

- both W bosons decay into leptons (≈10% of the time),
- one W boson decays into leptons, the other decays into a quark-antiquark pair (≈44% of the time),
- both W bosons decay into quark-antiquark pairs (≈46% of the time).

Analyzing different decay channels helps to improve statistics of top events, and studies of properties, as well as probing of physics beyond the Standard Model that could result in enhancement/depletion in some particular channel.



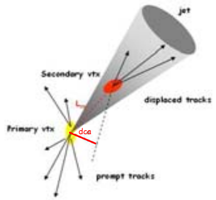
Top Quark Pair Production Cross-Section

Lepton+Track Channel

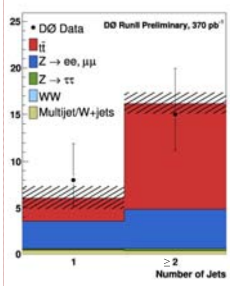
The lepton+track analysis measures the cross section in the dilepton channel. It improves the statistical sensitivity by identifying one lepton as an **isolated track** instead of a fully reconstructed lepton.

The preselection requires a high p_T isolated lepton (electron or muon), a high p_T isolated track, large missing transverse energy and at least one jet. The missing transverse energy cut depends on the type of lepton and on whether the invariant mass of the lepton and the isolated track is inside or outside the Z boson mass window.

The purity of the signal sample is enhanced by requiring at least one jet to be b-tagged. The b-tagging algorithm used is the **secondary vertex b-tagging algorithm** (SVT), which explicitly reconstructs vertices that are displaced from the primary vertex.



Events with both a high p_T isolated electron and a high p_T isolated muon reconstructed in the final state are vetoed in this analysis to allow a straightforward combination with the topological eμ analysis.



In the plot on the left the number of observed and predicted b-tagged events is shown as a function of the number of jets.

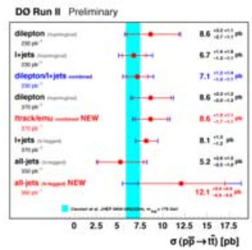
There are 23 events in data with ~8 background events expected, which gives a cross section of:

$7.1^{+2.6}_{-2.2}$ **(stat)** $^{+1.3}_{-1.3}$ **(syst) ±0.4(lumi) pb**

Cross Section Summary

The diagram on the bottom shows a summary of the most recent top quark pair production cross-section measurements performed in various channels by DØ in Run II.

All measurements are consistent with the Standard Model prediction and with each other.



Top Quark Properties

Top Quark Mass

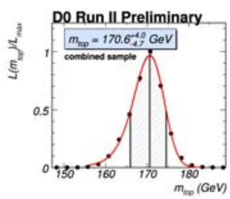
Matrix Element Method with b-tagging

The top quark mass is a fundamental parameter of the Standard Model, but it can not be predicted. One can measure the top quark mass in the lepton+jets channel. Events are selected requiring an isolated high p_T lepton, significant missing transverse energy and exactly four good jets. The preselected sample is split into three subsamples according to how many jets were b-tagged. A topological likelihood technique is used to estimate the signal and background fractions.

For the given event kinematics the probability to be signal or background is calculated, taking into account the differential cross-sections based on the **matrix elements**.

$$P_{t\bar{t}}(x; m_{top}, JES) = \frac{1}{\sigma(m_{top})}\int dq_1 dq_2 f(q) f(\bar{q}) d\sigma(y; m_{top}) W(x, y, JES)$$

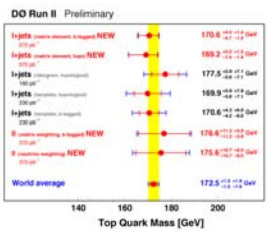
B-tagging information is used to improve the selection of the correct jet-parton assignment. An analytical likelihood method is then used to extract the top mass.



The result for the recombined event sample is

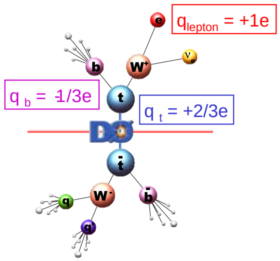
$m_{top} = 170.6^{+4.0}_{-4.7}$ **(stat+JES) ± 1.4 (syst) GeV**

The following plot shows a summary of the most recent top quark mass measurements by DØ.



Top Quark Charge

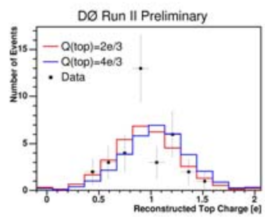
In the Standard Model the top quark has an electric charge of +2/3 e. An alternative theory suggests that the discovered particle is a charge -4/3 e quark. This analysis measures the charge of the top quark in the lepton+jets channel.



First, a pure sample is selected by requiring an isolated high p_T lepton, large missing transverse energy and four or more jets, of which at least two have to be b-tagged. A constrained kinematic fit assuming m_{top} = 175 GeV assigns one b-jet to the lepton and the other one to the light jets.

To determine the charge of the b-jet the **jet charge algorithm** uses the tracks inside the jet and sums up their electric charge weighted by their p_T. The b-jet charge is calibrated on muon-tagged b-jets in data.

The charge of the top quark is then determined from the charge of the lepton and of the b-jets. It is shown below together with the expected charge distribution for the Standard Model and the exotic scenario.



The data is in good agreement with the Standard Model. The hypothesis of an exotic quark with charge -4/3 e is excluded at 94% confidence level.