Fermi National Accelerator Laboratory

FERMILAB-Conf-92/105

Status Report from CDF

H. Grassmann

INFN Padova

April 1992

Summary of talk given at the *DESY Theory Workshop*, Hamburg, Germany, October 1991.

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

Status Report from CDF

Excerpt from a talk presented at the DESY Theory workshop 1991, Hamburg, by Hans Grassmann, INFN Padova

This paper discusses some of the more recent results from CDF. It is based on a talk given at the Desy Theory workshop "The Standard Model at high Temperature and Density". The paper emphasizes processes at parton q^2 which are high from the point of view of experiment. Possible implications on current developments in the analysis on theory and vice versa are discussed.

1. QCD related studies

1.1 W production and decay

1.1.1. *Testing structure functions*

Already some time ago CDF reported on the use of W's to investigate the proton structure function. The analysis uses the CDF W->μ(el)$^{\pm}\nu$ sample, the W's are from events where there is no jet with an Et(jet) larger than 10 GeV.

Different structure functions predict different W rapditiy distributions. Since one cannot measure the neutrino momentum component parallel to the proton beam, one cannot fully reconstruct the W's. Also statistical methods for reconstructing the W 4-momentum could not be applied. For a detailed discussion of this analysis the reader may refer to one of the papers [1,2,3].

Therefore CDF simply used the (pseudo) rapidity distributions of the charged leptons, instead of the W rapidity. As variable to be analysed we choose the lepton charge asymmetry $A(\eta)$. $A(\eta)$ is the relative difference between positive and negative leptons at a given rapidity η. This variable has the advantage that detection efficiencies essentially cancel. That results in very small systematic errors and it makes a direct comparison with theoretical predictions possible.

We show the measured charge asymmetry in figure 1. Muon and electron events are combined.

(*) Here and in the following the CDF data shown are always from the 1989/90 run. The integrated luminosity was about 4 pb^{-1}, depending on the kind of data sample used.

Also shown in figure 1 are theoretical predictions from different structure functions. The theoretical predictions in figure 1 are obtained by convoluting the proton structure functions with the W decay

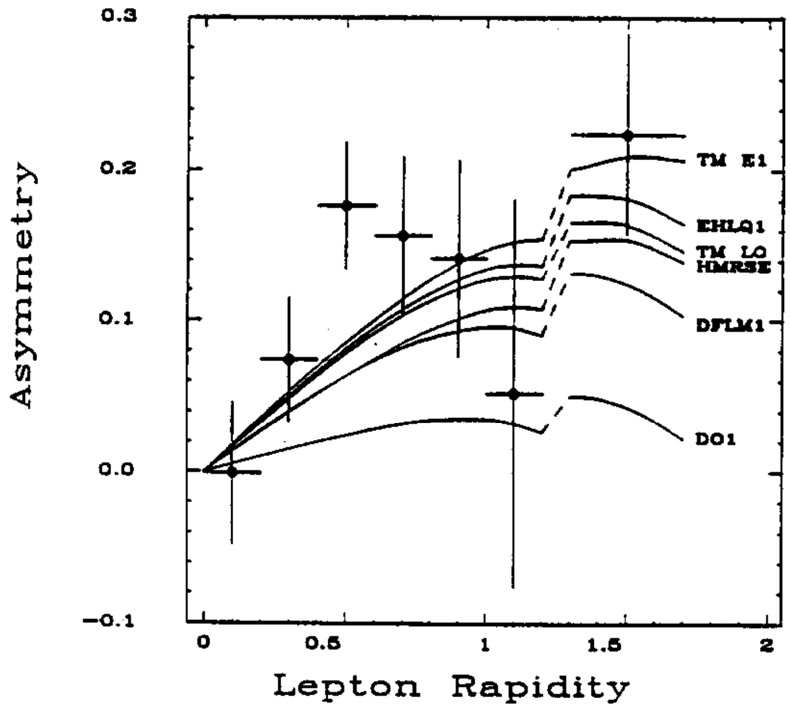

Figure 1 : lepton charge asymmetry as function of |rapidity|. Electron and muon results combined. The discontinuity in the theoretical predictions is due to a higher cut in the transverse mass of W's in the forward region of the detector.

pattern due to the V-A coupling. The error bars are statistical errors, the systematic errors are small compared to the statistical ones. Future runs will not only decrease the error bars but in addition we hope to improve the detection efficiency at large rapidities.

With respect to the next chapter we would like to mention that for pt(W)=0 the ambiguity in the neutrino momentum leads only to an ambiguity in the sign of $\cos\Theta^*$, not in its absolute value. (Θ^* is the angle between lepton and proton direction in the rest system of the W.) That can be seen easily by considering that $E_t(\nu)$ does not change under Lorentz transformations parallel to the beam axis. In both possible W rest frames $E_t(\nu)$ and therefore $|\cos\Theta^*|$ is the same. In principle a measurement of $|\cos\Theta^*|$ might also give information on the proton structure function. The analysis would be more difficult because detection inefficencies needed to be taken into account to a high accuracy.

1.1.2. *W polarisation*

In the last chapter we investigated the mechanism of W production by assuming a certain W decay pattern, that is a certain W polarisation. Now we would like to comment on possibilities to measure the W polarisation itself.

Theoretical predictions for the W polarisation have been made recently up to $O(\alpha_s^2)$ [4,5]. From both the CDF and DO experiments large numbers of W's are expected over the next years. Therefore it might become possible to test those QCD predictions, also at high values of pt(W).
If the structure functions are known, one might investigate the W polarisation again by means of the lepton asymmetry. Neither taking into account the neutrino nor the hadronic activity might however result in a loss of information too severe to allow for a meaningful measurement. More calculations are necessary to clarify this point.
Another test of the W polarisation seems possible by partially reconstructing the W.

The W decay lepton distribution can be written as [4]:

$$\alpha^*[d\sigma(\Theta,\phi)+d\sigma(\pi-\Theta,\phi+\pi)]/d\cos\Theta d\phi = \qquad (1)$$
$$1+\cos^2\Theta + 1/2A_0(1-3\cos^2\Theta) + A_1\sin2\Theta\cos\phi + 1/2A_2\sin^2\Theta\cos2$$

Θ and ϕ are the polar and azimuthal angles of the lepton in the W rest frame. A_0,A_1,A_2 characterize the polarisation of the W. The A_i's are functions of pt(W). Ref 5 claims that this formula is valid for both the Collins Soper and the Gottfried Jackson frame. Changing from one frame to the other only results in different functions A_i(pt(W)). As we see, the expression (1) is not sensitive to the sign of $\cos\Theta^*$, only $|\cos\Theta^*|$ enters. In the Collins Soper frame the two neutrino solutions result in the same angle ϕ and in the same value for $|\cos\Theta^*|$ [6].
So it should be possible to directly test it by experiment.
In an experiment which is fully sensitive to leptons from W decays this measurement would be independent from the proton structure function. In a real experiment corrections for detection inefficencies would have to be done. These corrections could be sensitive to the proton strcture functions. One would have to either use known structure functions, for example from HERA. Or one simply would use low pt W's as a gauge because the A_i in (1) are equal 0 for Pt(W)=0.

1.2 Photon angular distribution

Photons are defined as isolated electromagnetic clusters. The background, from the decay of neutral mesons, cannot be subtracted on an event to event basis. The transverse shower shape is used to calculate the probability of an event to be background or signal, each event gets weighted by that probability. More technical details on the event selection can be found in ref [7].
Θ^* is the angle between outgoing photon and incoming parton in the center of mass system of

photon+jet(s). The cuts are choosen such that the events which are used in the analysis are without bias in cosΘ*. The photon energy in the center of mass system is between 29.8 GeV and 47 GeV. The resulting cosΘ*(photon) distribution is shown in figure 2. It is compared to leading order and next to leading order predictions [8]. The inner errror bars in figure 2 are statistical errors, the outer ones are statistical and systematic errors combined. Data and prediction are normalised to each other in the range $|\cos\Theta^*| < 0.3$. Also shown in figure 2 is the cosΘ*(jet) distribution from jet events in a similar kinematic range [9].

The cosΘ*(γ) analysis separates signal (γ) from background (jets) by making use of a technical quality (the electromagnetic shower shape). We than see that signal and background events are very much different in their event structure, here cosΘ*. The argument can be inverted. If there is no difference between signal and background from the point of view of technical quality, then one

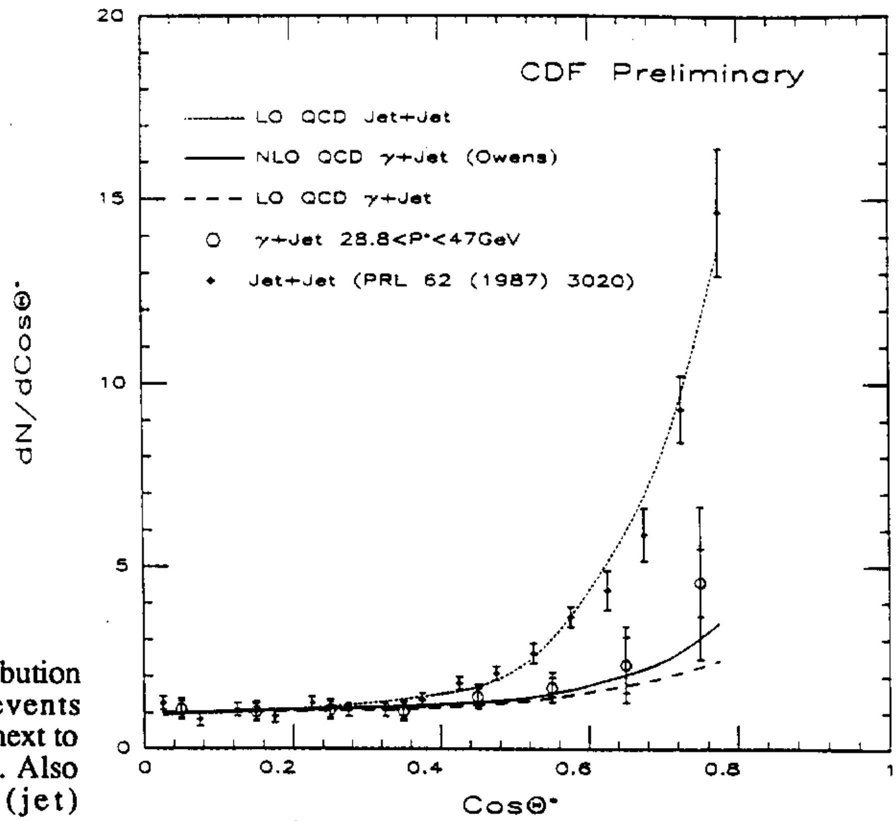

Figure 2 : CosΘ*(γ) distribution from photon+jet(s) events compared to leading and next to leading order predictions. Also shown is the cosΘ*(jet) distribution from di-jet events.

might use the event structure to separate signal from background. That for example might be applicable for the top search. Photons and W's are quite similar particles from some points of view. The sample of photon+jet events is essentially free of top events. A study of photon+jet events therefore might be useful in order to investigate W+jet events, which could have some contribution from top decays. In order to be aplicable for the top analysis statements of that kind need however to be made in a more quantitative way.

2, W->τν

The process W->τν is identified by the hadronic decays of the τ. τ's decaying hadronically cause quite narrow jets of low multiplcity in the CDF detector. W->τν events can enter our sample either through the missing transverse energy trigger. That trigger is however not very efficient because the trigger threshold is at 25 GeV and the two neutrinos in each W->τν event can partially cancel. Or the events can enter through a special τ trigger. This trigger uses the capabilty of CDF to measure the momentum of a track and the charged multiplicity of a jet already on the trigger level.

Many details of the τ analysis have been reported already elsewhere [10]. Essentially one requires missing transverse energy, a τ candidate jet which is very narrow in the calorimeter and a charged track in the CTC with pt > 5 GeV, pointing to that jet. After that selection the sample is still heavily contaminated with non-W QCD jet events. Events which have more than 1 track with pt > 1 GeV in a cone from 10^o to 30^o (isolation cone) around the jet are considered background. Those which do not have any track in that cone are τ candidates, they are a total of 250 events. The charged multiplicity ot the τ candidate sample of 250 events is shown in figure 3. From the shape of the background multiplicity distribution and from its absolute size we can determine the total number of W->τν events in our sample.

Taking all efficiencies into account and comparing to the cross section of W->el+ν events we deduce the ratio of the coupling constants g_{el}/g_t=0.97±0.07

Combining with the values obtained by UA1 and UA2 [11] one gets g_t/g_{el} = 1.00±0.05 .

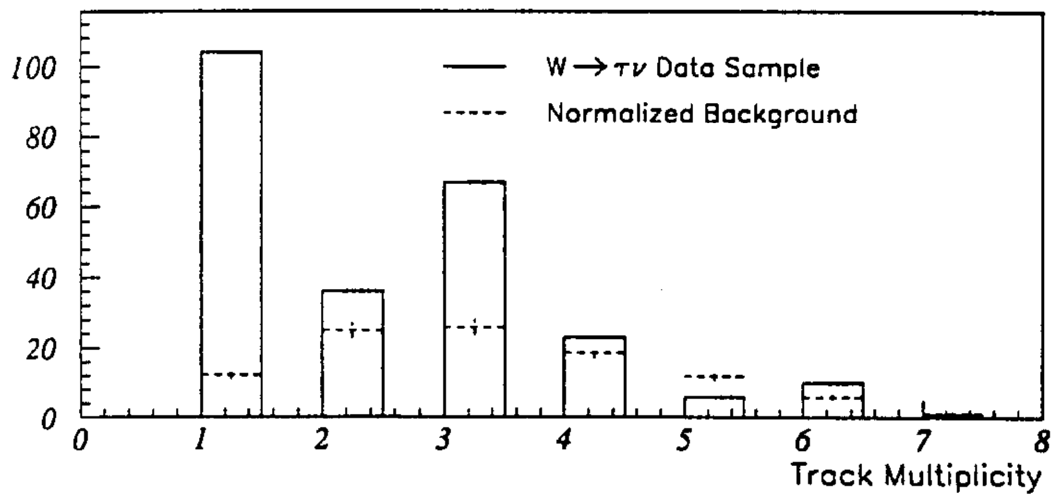

Figure 3 : multiplicity distribution of τ candidate jets. The dotted line is the background prediction on absolute scale.

The rather large errors on the CDF result are due to a lack of statistics. The tau trigger was installed during the run. The next run will have improved triggers already in place, so that the τ analysis will get much more sensitive.
In the context of this paper it is important to see that CDF indeed has a good capability of identifying τ's. Especially for one prong decays the background is very low, just after requiring a narrow jet, isolated in the CTC. Sophisticated likelihood methods are not needed. The tau signature might therefore be used to investigate other physics processes in the future.

3.Situation of the Top Search

We discuss Standard Model top decays only, that is we assume that each top decays in a W and a beauty quark.

3.1. Review

single lepton channel :
CDF arrived at a limit on m(top) by analysing a sample of W+ 2jet candidate events. If m(top) < m(W), then the W produced in the top decay is a virtual W. In that case the tranverse mass distribution of neutrino+charged lepton is different for top and for real (on shell) W events. The data were in very good agreement with being due to real W's only. From that it was possible to obtain a limit of m(top) > 77 GeV (95% c.l.). This analysis can not be applied for top masses larger than the W mass [12].
di-lepton channel :
Two leptons are required, either both of them from the decay of a W, or one from a W and the other one from a beauty decay. One such event is observed, having a high pt isolated muon and a high pt isolated electron of unlike sign. The background for that event would come from W pair production, some of it also from $Z \rightarrow \tau^+\tau^-$ or beauty events. The event is however not very likely in terms of background. Because one does not want to exclude a statistical fluctuation, based on one event, the event is not considered as a top event as far as a possible top discovery is concerned. For obtaining a limit on the top mass it is however considered as a top event of unkown mass. Taking this one event into account the analysis arrives at a limit of m(top) > 91 GeV (95%c.l.) [13].
One might naively think that the limit from the single lepton analysis should be stronger than the one from the di-lepton analysis because the number of di-lepton events is smaller due to the semileptonic branching ratios and due to inefficiencies in the lepton identification cuts. There is however a large

background to single lepton top events coming from QCD W+multi jet production, while the background to di-lepton events is very small.

3.2. Single lepton channel

We consider events with a W decaying into a charged lepton and a neutrino and with additional jet activity.
In the absence of a vertex detector there are no technical differences between top and background events in the CDF detector. There should however be differences in the event structure. For example, many jets from QCD W+jet events are from initial state radiation or they may be created by gluon splitting. In W+jet events which originated from a ttbar decay the jets as well as the W are decay products of a heavy object, centrally produced. Examples for variables which might be different for top and background are Et(jet), jet activity, mass (jet+jet),$\Delta\phi$(jet-jet) or cosΘ^*(jet).
In order to study these possible differences we need quantitatively understood monte carlo predictions for top and for QCD W+jet events.

3.2.1. *W+jet monte carlos*

For the simulation of W+multi jet events monte carlos are desireable which use QCD matrix elements. These monte carlos provide weighted events and the weight is correlated to the size of the matrix element for any given event. The matrixelement needs to be explicitely evaluated for each single event, a procedure which needs much computing time for W events with several jets [14]. In order to minimise the number of monte carlo events needed to arrive at certain statistical errors the weight distribution should be narrow. The standard procedure for achieving that is to subdivide the phase space in many cells. The volume of the cells is small in regions of phase space where the size of the matrix element is large. Because for each cell in phase space the same number of monte carlo events is produced the weight of all events will be about the same.
For processes with multi particle final states that procedure can cause problems because the number of cells becomes extremly large. An additional problem arises if the phase space is subdivided by a linear grid, in the sense that the binning of an axis is always the same in all regions of phase space. In such grids the cells cannot be adjusted independently from each other. As a result the weight distributions will extend over many orders of magnitude. From time to time an event will occur with a very large weight, introducing a kind of statistical error which is difficult to quantify.
A way out might be the use of non-linear grids where each cell can be adjusted independently. We did however not yet succeed to create or apply such grids. At least a preliminary solution might be the use of monte carlos which use a grid only in a few dimensions, for example the two

dimensions of the parton initial states. In all the remaining dimensions the events get created randomly.

A conclusive and satisfying solution to this problem was not found until now.A careful design of multi particle monte carlos will be of increasing importance as the physics analysis gets more sensitive to ever higher center of mass (parton) energies.

3.2.2. *Vecbos*

At the time being we are using the Vecbos monte carlo . Vecbos is able to produce W+n jet events, n=1,2,3,4. It populates the final state randomly [15].Vecbos uses the correct matrix elements in lowest order. The use of a lowest order matrix element means that one has to artificially choose a certain mass scale, q^2, for the strong coupling constant α_s and the results of the monte carlo will depend on this choice of $\alpha_s(q^2)$. The effect from ignoring higher order contributions can be estimated by varying the q^2 scale in α_s. For that a variety of q^2 scales are available in Vecbos. We created 100.000 W+3 jet events with q^2=pt(average)^2 and 60.000 events with q^2=m(W)^2. The cuts on the parton level where rap(parton) < 3.5 and pt(parton) > 12 GeV.

Vecbos was used by theorists till now, for their purposes the vecbos weight distributions are sufficiently narrow. When we need to compare to real data we have to apply a full detector simultaion and after that all the analysis cuts. For example the pt(parton) cuts have to be lower than the Et(jet) cuts because a low pt parton could create a jet at much higher energy due to the limited energy resolution and jet reconstructing capability of any experiment.

3.2.3. *Comparison of the W+jet monte carlo with data*

We are restricting ourselves to W+3 jet events to illustrate the situation.

Reconstruction of cosΘ^* :

Θ^*(jet) is the angle between jet and proton direction in the rest frame of the event, the neutrino longitudinal momentum is ignored. CosΘ^*(jet) values cannot be reconstructed precisely because of the unknown neutrino longitudinal momentum (compare chapter 1). We show cosΘ^*(jet) for Vecbos W+3 jet events in figure 4. The horizontal axis shows the true value of cosΘ^*(jet), which is known for monte carlo events. The y axis shows the value of cosΘ^* if we set the longitudinal neutrino momentum to 0. We see two things :

First, there is a large number of jets prediced in the forward direction. Vecbos produces events randomly in the final state, the forward direction does not get prefered. Therefore the Vecbos events with jets in the forward region will have large weights. Those events will cause large fluctuations in any distribution and therefore make the analysis problematic. It is also true that Vecbos might be less reliable for jets close to $|\cos\Theta^*(\text{jet})| = 1$ because of the missing higher orders.

Secondly we see from figure 4 that most events with a large true value of $\cos\Theta^*(\text{jet})$ get also reconstructed with a large $\cos\Theta^*(\text{jet})$. There are few events from $|\cos\Theta^*(\text{jet})|<0.8$ entering the region $|\cos\Theta^*(\text{jet})| > 0.8$ and vice versa.

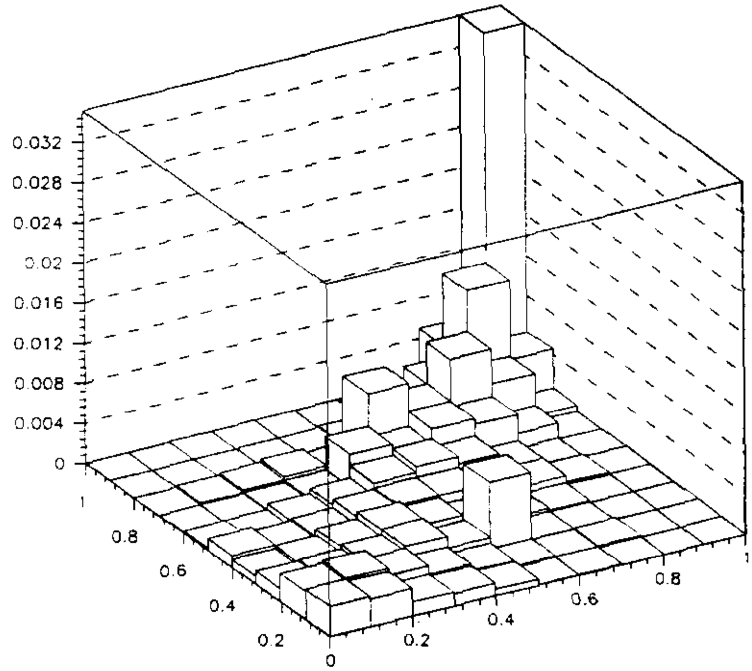

Figure 4 : $\cos\Theta^*(\text{jet})$ from W+3 jet Vecbos monte carlo events. The true value of $\cos\Theta^*(\text{jet})$ is plotted versus the reconstructed $\cos\Theta^*(\text{jet})$ if the neutrino longitudinal momentum is ignored.

Event selection :

The data are again from the 1989/90 run, we use both electron and muon W candidates.

The same cuts are applied to data and to monte carlo events.

In addition to lepton quality requirements we demand :

- Et(charged lepton) > 20 GeV
- missing transverse energy > 20 GeV
- transverse mass (lepton+missing energy) > 40 GeV
- 3 and only three jets Et(jet) > 15 GeV
- leading jet (called jet1) Et > 20 GeV

after these cuts we are left with 45 data events.In order to remove monte carlo events with a very large weight we reject events which have jets in the forward direction by the additional cuts :

- $|\cos\Theta^*(\text{jet1})| < 0.8$, $|\cos Q^*(\text{jet2,3})| < 0.9$

We get a total of 20 data events. The effect of the cuts in cosΘ*(jet) was to remove 25 events. The Vecbos prediction is 21 events for $q^2=m(W)^2$ and 11 events for $q^2=pt(average)^2$. In the following plots we always normalise the mone carlo events to the 20 data events.

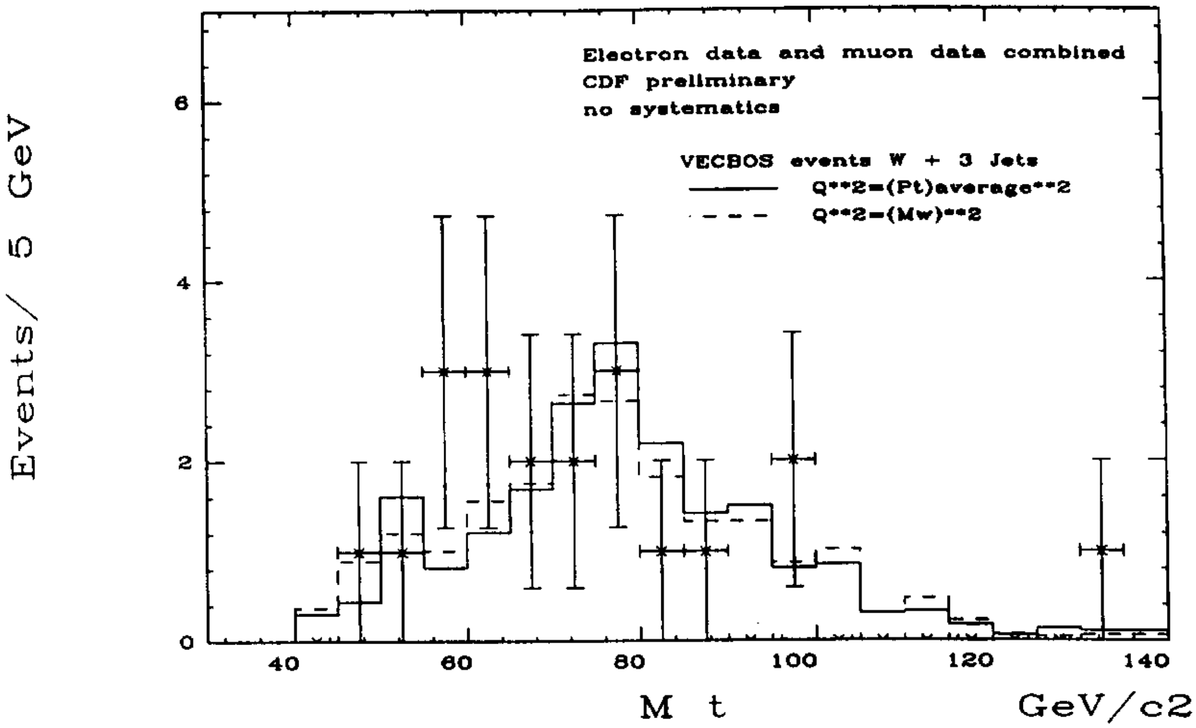

Figure 5: transverse mass (charged lepton+neutrino) of the 20 W+3 jet events.

We show the transverese mass distribution of these 20 events in figure 5. Also shown is the prediction from our monte carlo for the two choices of q^2 mentioned before. The reasonable agreement between monte carlo and data shows that our sample is dominated by good W events. A contribution of several non-W background events cannot be excluded.

As an example we show a comparison for the Et(jet 3) and for the cosΘ*(jet 3) spectra in figures 6 and 7. The agreement seems to be not bad. But we did not do any background subtraction nor did we discuss systematic errors. So any statement of a more physics related nature should not be made at that point. (For the other Et and CosΘ* spectra, which are not shown, the agreement between data and prediction is about as good as for figures 6 and 7.)

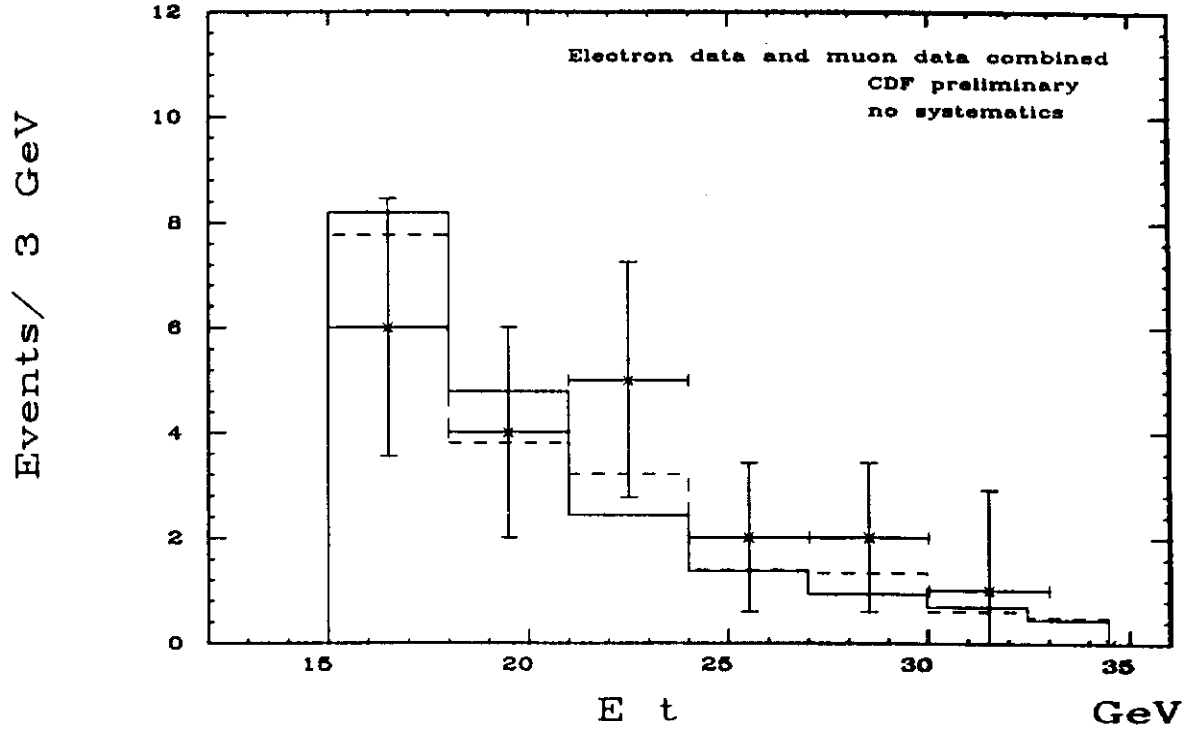

Figure 6 : Et(jet3) of W+3 jet events. Vecbos prediction normalised to the 20 data events. The vecbos prediction is shown for two different choices of q^2.

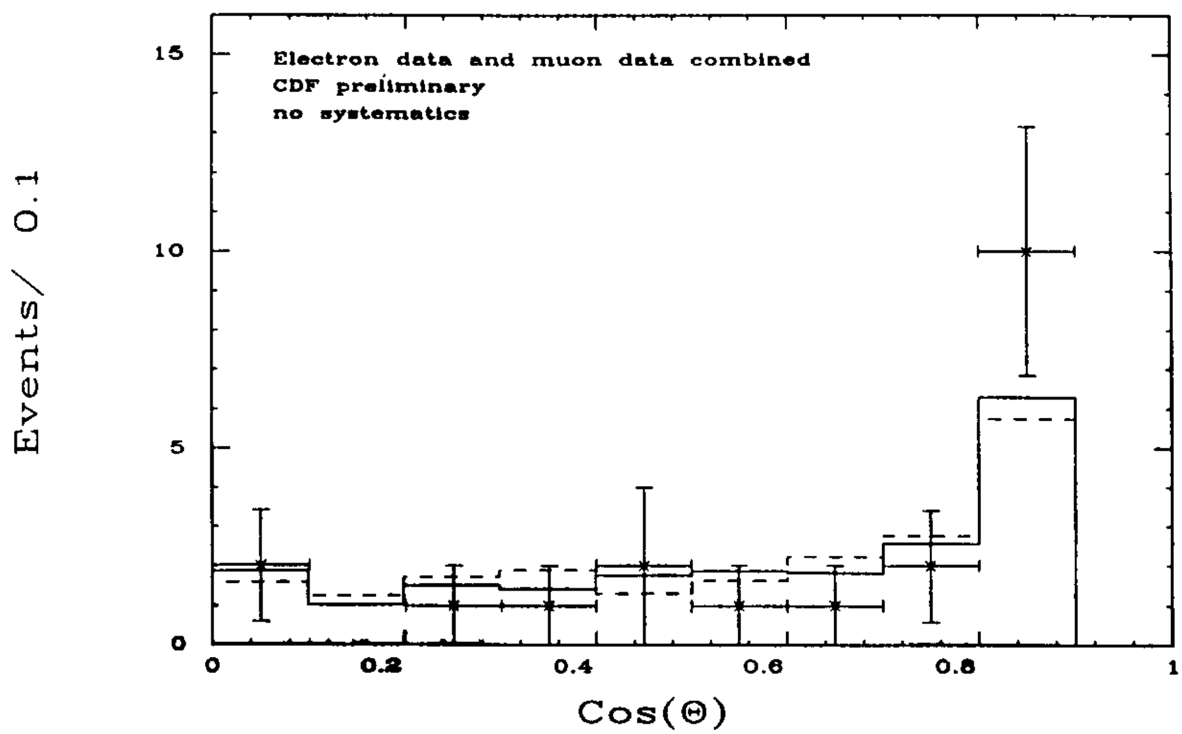

Figure 7 : cosΘ*(jet3) of W+3 jet events. Vecbos prediction normalised to the 20 data events. The vecbos prediction is shown for two different choices of q^2.

Additional work on Vecbos is going on in order to include higher orders and in order to make the weight distribution narrower [16]. Also interesting results from other monte carlo generators and from new phase space generators are hoped for like Herwig, Octopus [17], Papageno or any other completely new development. A very interesting problem will be the possible use of monte carlos which do not use the full matrix element but some approximation in order to safe CPU time.

3.3. Top monte carlos

A crucial part of the top analysis will concern the jet activity in single lepton top events. The top monte carlos therefore need to take jets from QCD processes into account. Differences regarding QCD radiation were found for example between the Isajet and the Papageno monte carlos. That indicates that also the top monte carlos need more studies in order to arrive at final conclusions.

3.4. Application of the study of the event structure

Once the event structure of top and background events is well understood a top likelihood can be assigned to each event. More straightforward one could subdivide the sample in two subsamples such that one of them would be enriched with top candidates.

3.4.1. *Single lepton channel*

An example for such a subdivision was given in the previous chapter. We applied the cuts in $\cos\Theta^*$(jet) because the monte carlo creates problems for large values of $\cos\Theta^*$(jet). Those cuts are however suited for the top analysis as well. They rejected more than half of the data events, for top events they would be very efficient. Using the event structure helps to look for top in the single lepton + jets channel.

3.4.2. *b tagging*

CDF expects to have a silicon vertex detector available for the next run which will be able to detect the secondary vertex from b decays. b decays should only show up in events which have a large top likelihood.

Another way to tag b's is the search for leptonic b decays in W+jet events. The present CDF analysis is using this technique. One requires a low pt muon which is separated from the two leading jets in the events. In figure 8 we show the distance in space between the muon and the nearest leading jet for top events of m(top)=90 GeV (dotted line) and for W+jet data [13]. A cut $\Delta R(\mu\text{-jet}) > 0.5$ is applied to search for top events. At small ΔR there are 'muons' from background, mostly K or π decays or from leakage out of the calorimeter. For the future we will have to look for top also at higher masses. Than the b's will be of higher energy and the muons will be expected to be in a high Et jet. Though the muon background will be reduced very much by ongoing upgrading programs it still should be useful to assign a probability to each jet in a W+jet event to be from QCD or not, based on the configuration of the event.

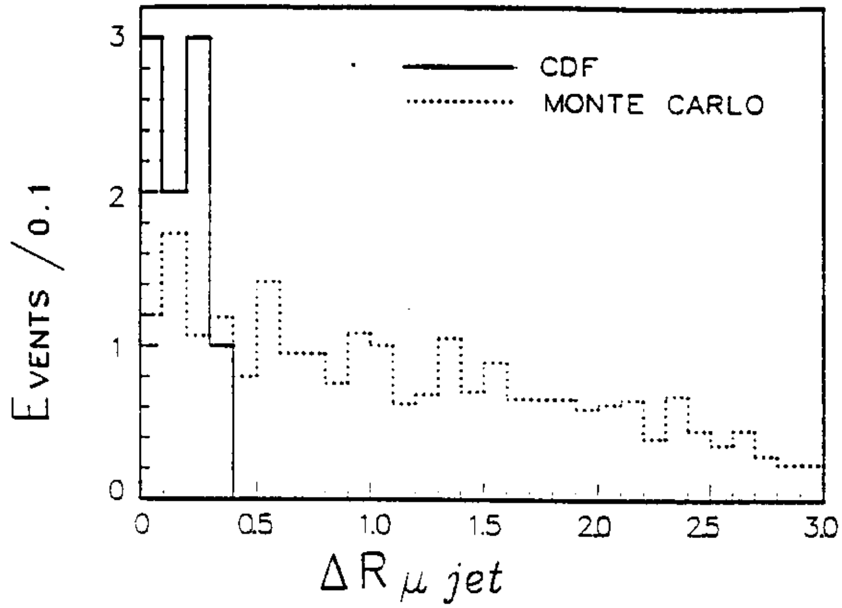

Figure 8 : ΔR(μ-leading jet) in W+2 jet events. Dotted line from Isajet prediction at m(top) = 90 GeV. Solid line are CDF data.

3.4.2. tau search

A very similar argument can be made for the search for electron or muon + tau events. CDF has a good capability to identify τ's (chapter 2), but that is a rather new analysis and so the information from the event structure might be welcome for el(μ) + τ candidates.

4. Conclusion

Even after several years of succesful scientific work the existing CDF data are not yet fully analysed and significant progress is still being made. CDF is moving into new fields of analysis, and in that process a close collaboration between experimental and theoretical physicists becomes ever more important. We hope that this writeup shows that such a collaboration can be done and that it is very productive.

For the long term future it is interesting to remember that at both the SPS and the Tevatron collider new experiments needed some time for developing analysis tools. A close collaboration between theorists and experimentalists will help to avoid delays once the next big hadron collider gets operational.

Acknowledgments
Much of the work described in this note would not have been possible withouth the contributions of my younger colleagues M. Cobal and S.Leone. W.Giele's work on W+jet monte carlos was essential. I also would like to thank G.Bellettini for his support and for many fruitful discussions.

References

1, Thesis S. Leone, INFN, PI-AE90/7.

2, F.Abe et al.(CDF coll.),'Lepton Asymmetry in W Decays from ppbar Collisions at $\sqrt{s}$=1.8 TeV',submitted to Phys.Rev.Letters, Sept.1990

3, H.Grassmann,'New Results from W and Z at CDF',Les Rencontres de Physique de la Vallee d'Aoste(337),1990.

4, E.Mirkes, J.G.Koerner, G.A.Schuler, Phys.Lett.B 259,151,'O(α_s^2) corrections to high qt-polarized gauge boson production at hadron colliders'

5, E.Mirkes,XXVI Rencontres di Moriond, High Energy Hadronic Interactions, March 1991, to be published

6, K.Hagiwara, K. Hikasa, N.Kai,'Parity-odd asymmetries in W-jet events at hadron colliders',Phys.Rev.Letters, 52 (1076), 1984.

7, R.Harris, Proceedings Particles and Fields 91, University of Vancouver, Vancouver, British Columbia, Canada,.

8, leading order caluclations from Papageno monte carlo, I,Hinchcliffe, private communication. Next to leading order from J.Owens, private communication.

9, A.Abe et al., CDF, Phys.Rev. Lett. 62 (1989) 3020.

10, A.Roodman, Proceedings Particles and Fields 91, University of Vancouver, Vancouver, British Columbia, Canada,.

11, CERN-PPE/91-69, Phys.Lett.B185,233.

12, F.Abe et al.(CDF coll.),'A Search for the Top Quark in the Reaction PPbar -> Electron+Jets at 1800 GeV',Phys.Rev.Letter 64, 1990. and F.Abe et al.(CDF coll.),'Top Quark Search in the Electron+Jet Channel in proton-antiproton Collission at 1.8 TeV',Phys.Rev.D. 43 (664), 1991.

13, F.Abe et al.(CDF coll.),'A Lower Limit in the Top Quark Mass from Events with two Leptons in ppbar Collisions at $\sqrt{s}$=1.8 TeV',submitted to Phys.Rev.Lett.. and F.Abe et al.(CDF coll.), 'A Limit on the Top Quark Mass from Final States with two Leptons in proton-antiproton Collisions at $\sqrt{s}$=1800 GeV',submitted to Phys.Rev.D.

14, Thesis W.Giele, University Leiden

15, Fermilab-Pub 90/213T. Fermilab-conf-90/229T. Cavendish-HEP-90/26. W.Giele,Proceedings Aachen LHC Workshop.

16, W.Giele, private comunication.

17, D.Kosower, Fermilab 90/85-T.