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## **QCD and Heavy Flavor Physics at High Energy**

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# QCD AND HEAVY FLAVOR PHYSICS AT HIGH ENERGY

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This talk summarizes recent results from the Tevatron Collider and HERA on QCD and Heavy Flavor physics

## 1 Introduction

This talk covers recent results obtained at the Fermilab Tevatron by the CDF and D0 collaborations and at HERA by the H1 and ZEUS collaborations on the subject of QCD and Heavy Flavor physics.

At the Tevatron Collider a 900 GeV proton beam collides with a 900 GeV anti-proton beam leading to a total center-of-mass energy of 1.8 TeV, the highest currently available. The bulk of the data collected by the CDF and D0 experiments has been recorded during Run I of the Tevatron, with each experiment accumulating on the order of  $100 \text{ pb}^{-1}$ . The Tevatron is currently undergoing major changes to increase its luminosity by more than one order of magnitude. It is expected to start running again sometimes early in the year 2000 with the goal of integrating  $\sim 2 \text{ fb}^{-1}$  in a couple of years.

At HERA 27.5 GeV positrons collide on 820 GeV protons for a center-of-mass energy of about 300 GeV. The analyses reported here by the H1 and ZEUS experiments are based on a set of data collected from 1994 till 1997 corresponding to about 40-50  $\text{pb}^{-1}$  per experiment. The high end of the  $Q^2$  range and proton  $x$  explored by HERA overlaps with the Tevatron range. This implies some level of interplay between the measurements at the two machines. The HERA machine will approximately double the statistics in the years 1998-99 running in the electron-proton mode. Further upgrades will allow in the year 2000 delivery of about 150  $\text{pb}^{-1}$ /year per experiment and the use of polarized electron/positron beams.

## 2 QCD

This section is a summary of the QCD talks and, also, topics of heavy flavor and vector boson production cross sections, even if they were presented in the heavy quark or electro-weak physics sessions.

### 2.1 Inclusive distributions

The predictions of QCD are in general quite successful at high  $Q^2$ , since the coupling constant becomes smaller and higher order corrections are consequently less important. Inclusive cross section measurements both at the Tevatron and at HERA show an impressive agreement between experiment and theory over a large range of  $Q^2$  corresponding to a cross section variation of many orders of magnitude. Devia-

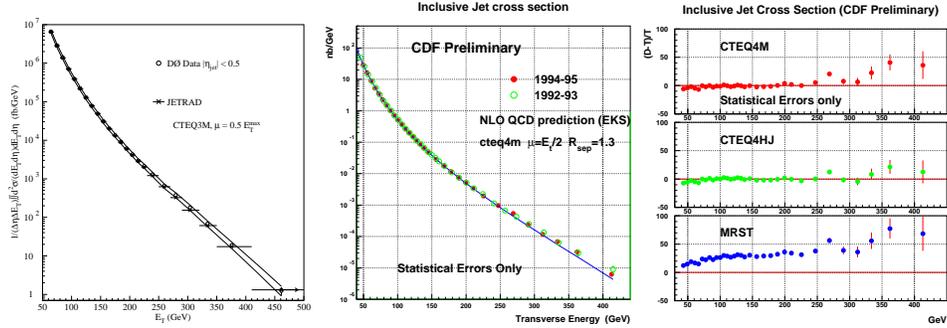


Figure 1. D0 (left) and CDF (center) inclusive jet cross sections as a function of jet  $E_t$ ; (right) CDF cross section from run 1B data compared to theory with different pdf choices

tions from the expected behavior would be very interesting since they could signal the emergence of new physics. The inclusive jet cross sections recently measured by CDF<sup>1</sup> and D0<sup>2</sup> with the full run 1 statistics and the combined H1 and ZEUS neutral and charged current cross sections, including all 1997 data, are shown in fig. 1 and fig. 2. A closer look at these results can be obtained by plotting on a linear scale the ratio of the difference between data and theory over the theory or just the ratio of data over theory. These comparisons show a rise above what is expected from theory in the high end region of the spectrum for the CDF data. Such a rise is not observed in the D0 data. A direct comparison of CDF and D0 jet cross sections is shown in fig. 2. Except for a small normalization shift, the two experiment are in agreement once systematic errors are taken into account. These comparisons are sensitive to the choice of parton distribution function (pdf), as shown by the right plot of fig. 1; CTEQ4HJ, which has an enhanced gluon content at high  $x$ <sup>3</sup>, is the one preferred by CDF data.

Recent results from ZEUS and H1<sup>4</sup> do not show anymore the excess at high  $Q^2$  reported in 1997. The present neutral and charged current inclusive cross-sections are consistent with theory as seen in fig. 2.

## 2.2 Proton structure

Pdf's are critical in obtaining predictions from QCD calculations. A key role in their determination is played by deep inelastic scattering measurements. The HERA experiments, with the use of 1996 and 1997 data, have been able to reduce the uncertainty in the determination of  $F_2$  to about 3-4%, as shown in fig. 3. This result now spans 4 orders of magnitude in  $x$  and its accuracy is dominated by the systematics<sup>5</sup>. The large statistics available has allowed testing the  $Q^2$  evolution of the proton structure function from  $Q^2$  of tens of  $\text{GeV}^2$  to  $Q^2 \sim 5000 \text{ GeV}^2$  and check the extrapolation to fixed target data at lower  $Q^2$ . The agreement between the data and the prediction of the DGLAP evolution equation over a large range of  $Q^2$  and  $x$  is remarkable as shown in the central plot of fig. 3.

At HERA information on the gluon density can be obtained by fits to the  $F_2$

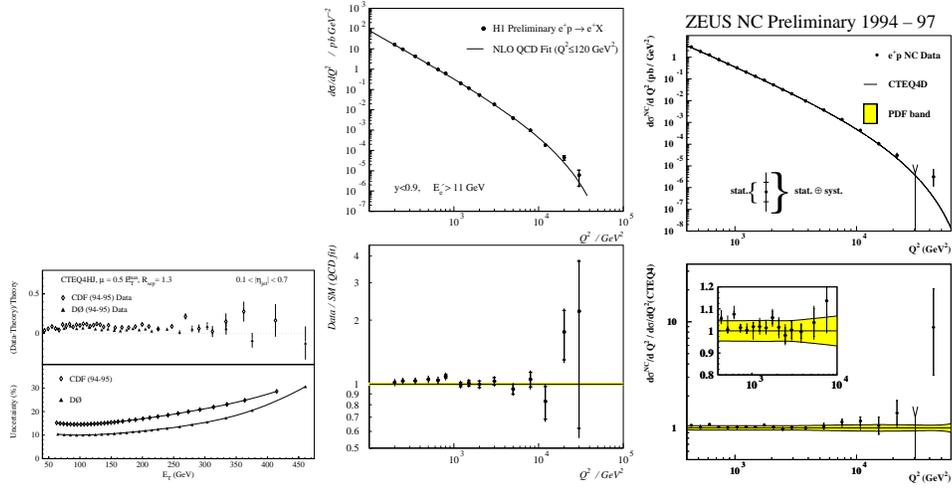


Figure 2. Comparison between CDF and D0 inclusive jet cross sections (left); neutral current inclusive cross sections at H1 (center) and ZEUS (right)

evolution, from measurements of di-jet production or from measurements of heavy flavor production. In particular new measurements of  $D^*$  production are available from both H1 and ZEUS <sup>5</sup>. On the right plot of fig. 3 we see a comparison of the  $F_2$  fit and the results obtained using charm production data as performed by H1. A good understanding of the gluon structure function is very important to compare experiment and theory at HERA and even more at the Tevatron, where most processes involve gluons in the initial state. In particular it would be interesting to further constrain the gluon pdf at high  $x$  and high  $Q^2$ . We notice that the maximum gluon  $x$  reached by the HERA measurements is still in the  $10^{-2}$  range, while the high end of the Tevatron data is sensitive to gluons in the  $x$  range  $10^{-1}$ -0.8. This high  $x$  region is also covered by fixed target direct photon production <sup>6</sup>.

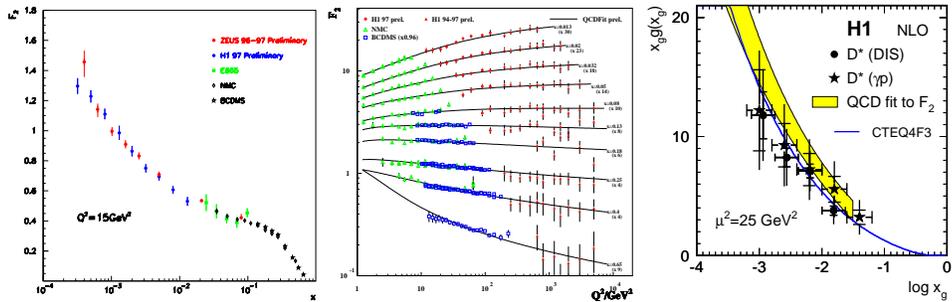


Figure 3. (Left) Latest  $F_2$  measurement at HERA, (center)  $Q^2$  evolution of  $F_2$ , (right) H1 measurements of the gluon density in the proton compared to the CTEQ4F3 pdf

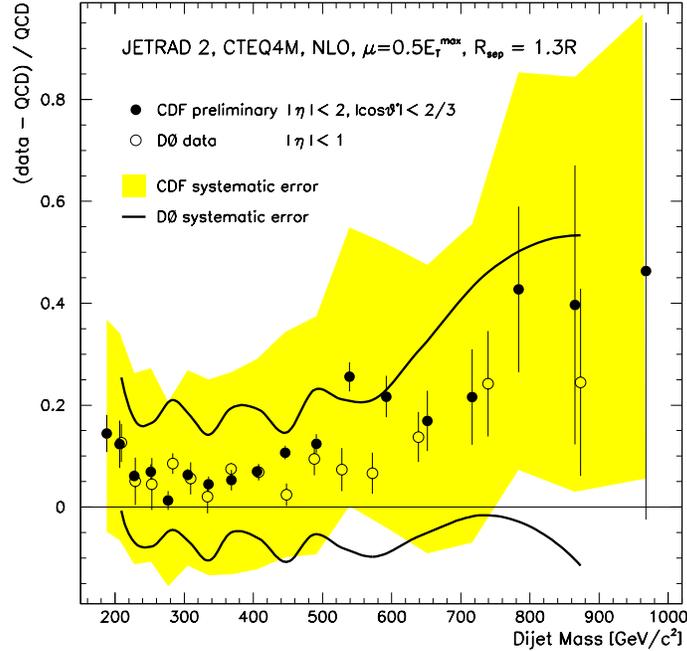


Figure 4. Comparison of CDF and D0 di-jet mass cross sections with NLO CDF predictions

### 2.3 Di-jet cross sections

Events where two jets are clearly identified are used at the Tevatron to test the theory at a deeper level. Both experiments have measured the di-jet mass cross section and are in good agreement <sup>7</sup> as shown in fig. 4. The data are consistent, within the systematic errors, with NLO QCD predictions although an excess is seen at high masses. The excess at high masses is consistent with that predicted using the CTEQ4HJ pdf. D0 has used the di-jet mass cross section ratio of  $|\eta| < 0.5$  over  $0.5 < |\eta| < 1.0$  to test for compositeness, excluding a compositeness scale of 2.4 TeV at the 95% confidence level <sup>8</sup>. This limit is better than the previous results from di-jet angular distributions <sup>9</sup>.

CDF measures the jet cross section as a function of the  $E_t$  of one central jet ( $0.1 < |\eta| < 0.7$ ) after requiring that the other jet, with  $E_t > 10\text{GeV}$  is in one of four possible  $\eta$  ranges <sup>7</sup>. The results are shown in the left plot of fig. 5 compared with NLO predictions using the CTEQ4M, CTEQ4HJ <sup>3</sup> and MRST <sup>10</sup> pdf's. Again we observe a rise at high  $E_t$  that is tracked best by CTEQ4HJ. This way of presenting the information directly probes higher  $x$  values than the inclusive jet cross section, and isolates much better specific ranges of  $Q^2$  and  $x$ . In the right plot of fig. 5 we show the average parton level  $t$  and maximum  $x$  value for each of the measured

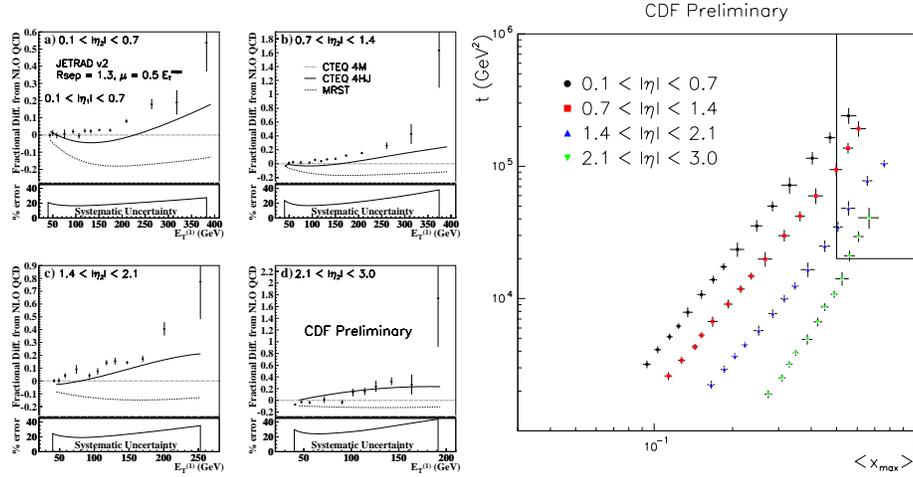


Figure 5. (left) Comparison of the CDF differential di-jet cross section to NLO QCD predictions (right) the parton kinematics reach of the CDF differential analysis. The box in the upper right corner indicates where a possible excess at HERA has been probed

points. The box in the upper left corner is the region of phase space corresponding to the highest  $Q^2$  which can be probed by the inclusive neutral and charged current distributions at HERA.

D0 has recently presented a similar measurement <sup>7</sup>, shown in fig. 6. Relative to the CDF measurement, they also split their data between the case when the central jet is on the same or opposite  $\eta$  side of the probe jet. They use CTEQ4M for their

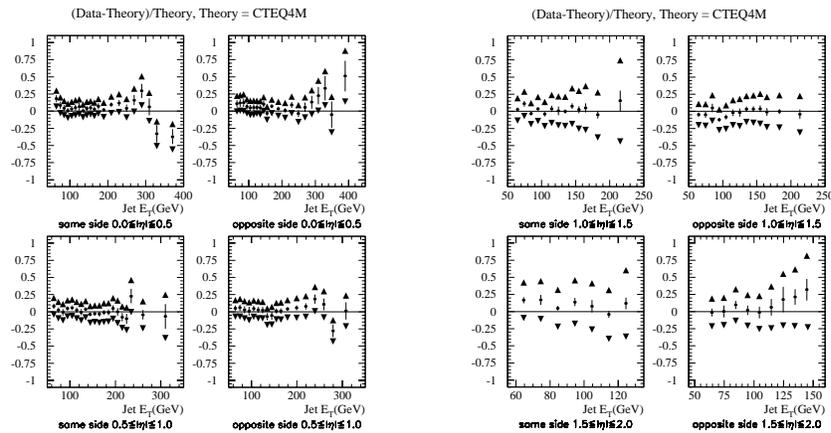


Figure 6. Comparison of the D0 differential di-jet cross section to NLO QCD predictions: (left) bins  $0.0 < |\eta| < 0.5$  and  $0.5 < |\eta| < 1.0$ , (right) bins  $1.0 < |\eta| < 1.5$  and  $1.5 < |\eta| < 2.0$

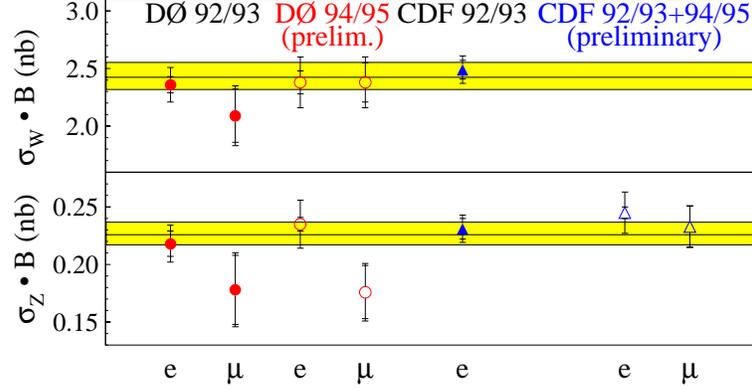


Figure 7. W and Z measured production cross sections compared to theoretical predictions

comparison with theory and do not observe any obvious rise at high  $E_t$ .

#### 2.4 Production of W's and Z's

The production cross sections of W's and Z's are calculated by NNLO QCD to an accuracy of  $\sim 5\%$ <sup>11</sup>. In fig. 7 we show the measurements of CDF and D0 compared with theory predictions<sup>12</sup>. The accuracy of the experiments and theory are in this case comparable and the agreement is good. It is interesting to notice that the agreement between the measurements of CDF and D0 would be even better if they normalized their luminosity to the same total inelastic cross section.

The production of W's in association with jets is a very important background

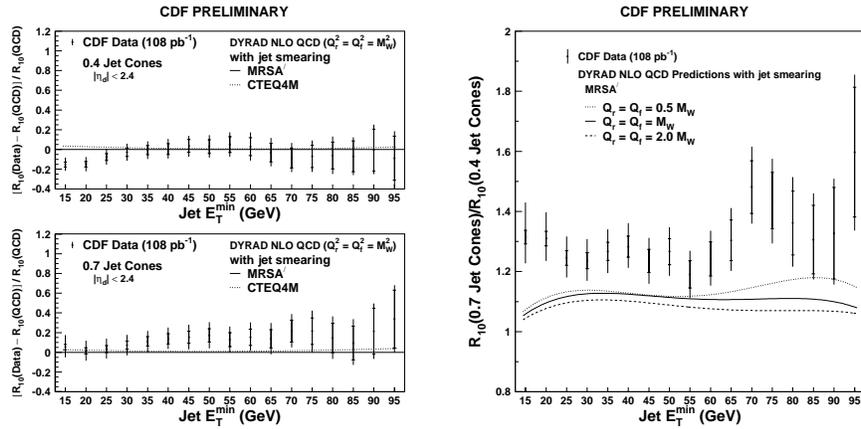


Figure 8. (left) Relative deviation from NLO QCD theory of the ratio  $R_{10}$  as measured by CDF, (right) The ratio of  $R_{10}$  with jet cone of 0.7 and 0.4 for CDF data and NLO QCD

for many high mass searches at hadronic colliders and is a good test of higher order QCD calculations.

CDF has recently measured the ratio,  $R_{10}$ , of  $W+\geq 1$  jet to inclusive  $W$  production using both jet cone of 0.4 and 0.7<sup>13</sup>. The comparison of these measurements with NLO QCD predictions is shown in the left plot of fig. 8 and indicates agreement for both cone sizes. If we plot however the ratio between  $R_{10}$  obtained with a 0.7 cone to that obtained with a 0.4 cone (fig. 8 (right)) we find the CDF data higher than the theory. This may be another indication that jets at the Tevatron are broader than theoretical predictions based on NLO QCD.

### 2.5 Heavy Flavor Production

The production of heavy flavors is particularly interesting since it introduces another natural scale, the quark mass, into the QCD calculations. For high quark mass, as in the case of the top quark, this scale is very large and QCD predictions have reached a 5% level of accuracy<sup>14</sup>. In the left plot of fig. 9 we show the CDF<sup>15,17</sup> and D0<sup>16,17</sup> measurements compared to various theoretical calculations<sup>14</sup>. Both experiments combine the measurements obtained using different top decay modes and selection criteria to reduce the experimental error: the combined result is  $\sigma_{t\bar{t}} = 5.6 \pm 1.8$  pb for D0 and  $7.6^{+1.8}_{-1.5}$  pb for CDF. This is to be compared to a range of theory predictions between 4.7 and 5.5. The CDF result is somewhat high, but still consistent within the errors.

The agreement with theory is not as good in the case of  $b\bar{b}$  production. In fig. 9 we show a comparison of the CDF<sup>18,20</sup> and D0<sup>19,20</sup> measurements with the prediction from NLO QCD calculation<sup>21</sup>. While the two experiments agree, these results are about a factor 2.5 higher than the central theory curve. D0 measures

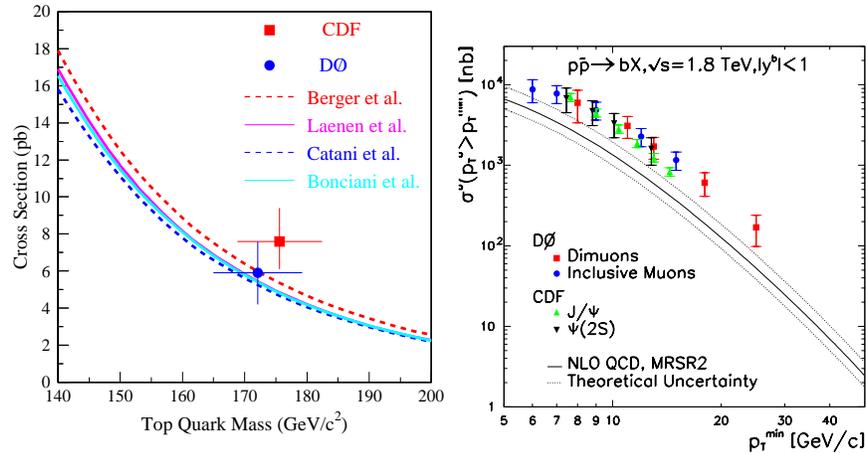


Figure 9. (left) The CDF and D0 top cross sections compared to several calculations; (right) the bottom quark integral production cross section as a function of the minimum b-quark  $p_T$ . CDF and D0 data compared to NLO QCD predictions

an even larger discrepancy factor,  $\sim 3.6 \pm 0.8$  in the forward rapidity region. The error however is large enough to be consistent with the central region. In general the problem with b cross sections appears to be that of overall normalization, while the shapes, including correlations between the two b quarks in the event, are well described by higher order QCD<sup>22,20</sup>. It has been shown at this conference that new developments based on the Variable Flavor Number approach could lead to improvements in the agreement with the experiments<sup>23</sup>.

The prompt production cross section of  $J/\psi$ 's and  $\psi'$  has produced considerable interest in the past year after the large discrepancies found at the Tevatron between the experimental observations of  $\psi$  and  $\psi'$  production<sup>24</sup> and the expectation from color singlet models<sup>25</sup>. New calculations<sup>26</sup> including color octet contributions have improved significantly the agreement with the Tevatron data<sup>27</sup>.

At Hera the agreement of the  $\psi$  photo-production cross section with color octet predictions<sup>26</sup> is not as good and requires the introduction of a constituent motion contribution with  $kT \sim 1$  GeV/c to describe the data, as shown in fig. 10, while a NLO color singlet calculation appears to describe the data better<sup>28,29</sup>.  $\psi$ 's produced at HERA have a much lower  $p_t$  than those produced at the Tevatron. Therefore significant perturbative and non-perturbative soft-physics effects could make testing color-octet predictions at HERA particularly difficult<sup>26</sup>. The dependence of  $J/\psi$  production at HERA as a function of the available center of mass energy is well described by the NLO calculation<sup>29</sup> and is quite sensitive to the gluon structure function as seen in the right plot of fig. 10.

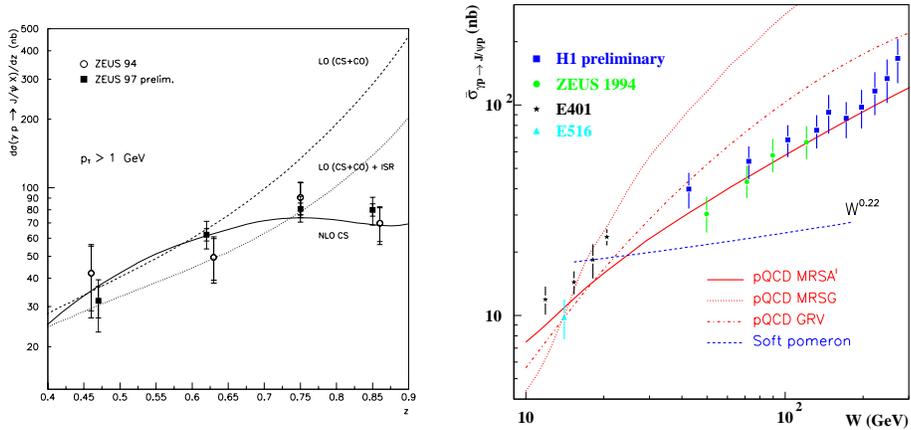


Figure 10. (left)  $J/\psi$  photo-production cross section as a function of the fraction of  $\gamma$  momentum carried by the  $J/\psi$  at HERA; (right)  $J/\psi$  photo-production cross section as a function of the c.m. energy of the  $proton - \gamma$  scattering compared to several theoretical models

## 2.6 Rapidity Gap Physics

Rapidity gaps are defined as the absence of particles in a certain rapidity region. They are the distinct signature of the exchange of a colorless object, also known as Pomeron in low energy phenomenology. A number of rapidity gap events, in excess of what is expected from fluctuations of processes involving the exchange of colored objects, has been observed both at Hera and at the Tevatron. Special cases of rapidity gap processes are single diffraction and double Pomeron exchange.

Events with rapidity gap exhibit features that suggest a hard Pomeron structure. For instance in fig. 11 we see how di-jet events with a single or double gap have similar jet- $E_t$  distributions as inclusive 2-jet events at the Tevatron<sup>30,31</sup>. Other features are the diffractive production of W bosons and bottom quarks as observed by CDF<sup>32</sup>.

At Hera both ZEUS<sup>33</sup> and H1<sup>33</sup> have measured the diffractive structure function  $F_2^{D(3)}$ . This structure function can be interpreted as the product of a Pomeron flux and a Pomeron structure function, whose  $Q^2$  evolution is determined by the DGLAP equation. Fits to this  $Q^2$  evolution prefer a large gluon fraction in the Pomeron:  $\sim 80\%$  at  $Q^2 = 75 \text{ GeV}^2$ <sup>33</sup>.

Assuming these Pomeron structure functions and factorization one can use this approach to describe diffraction results at the Tevatron. Published CDF results indicate consistency with the large gluon content of the Pomeron<sup>32</sup>, but have otherwise large normalization problems with this interpretation (fig. 11). More recent measurements of diffractive di-jet production with recoil beam particle tagging at CDF allow a direct measurement of the Pomeron structure function and confirm the normalization issue<sup>30</sup>. A better agreement can be found by redefining the Pomeron flux as suggested by some authors<sup>34</sup>, though CDF still observes a steeper

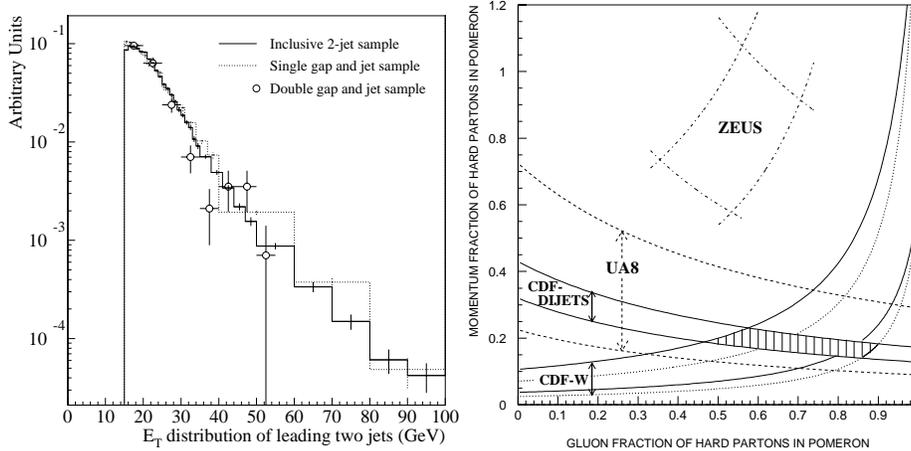


Figure 11. (left) Comparison of  $E_t$  distributions of inclusive 2-jet events (no gap), single gap plus jet events and double gap plus jet events as measured by the D0 experiment; (right) the flux discrepancy factor  $D$  versus the the gluon fraction of the Pomeron. W and di-jet results from CDF as shown along with ZEUS and UA8 results.

slope than HERA at low  $\beta$ , the parton momentum fraction in the Pomeron.

### 3 Heavy Flavours

#### 3.1 Top quark

The study of top quark at the Tevatron has been extremely successful<sup>35,36</sup>. CDF<sup>17,37</sup> and D0<sup>17,38</sup> have measured the top quark mass using a variety of techniques and top data subsets. Both experiments derive most of their resolution from the lepton plus jet sample, where one of the two real W's in the event decays semi-leptonically in the electron or muon channel, while the other W decays into quark pairs. Mass fits to this specific sub-sample are shown in fig. 12 for both CDF and D0; a summary of all results is shown in table 1. We notice how the Tevatron average has a 3% error only. The top mass is an important parameter of the Standard Model, in particular it is needed to constrain the Higgs mass.

The Tevatron experiments have studied several features of top quark production and decay:  $p_t$ ,  $\eta$ , mass of the  $t\bar{t}$  system (fig. 13), W polarization, top-antitop spin correlations<sup>39,40</sup>. All of these studies suffer from lack of statistics; there are however, within the attainable accuracy, no significant deviations from the Standard Model predictions.

Searches for single top production from both CDF and D0 have so far failed to observe a signal<sup>40</sup>. CDF has set an upper limit of 15 pb to the single top production cross section; this limit is about a factor seven larger than what expected from the

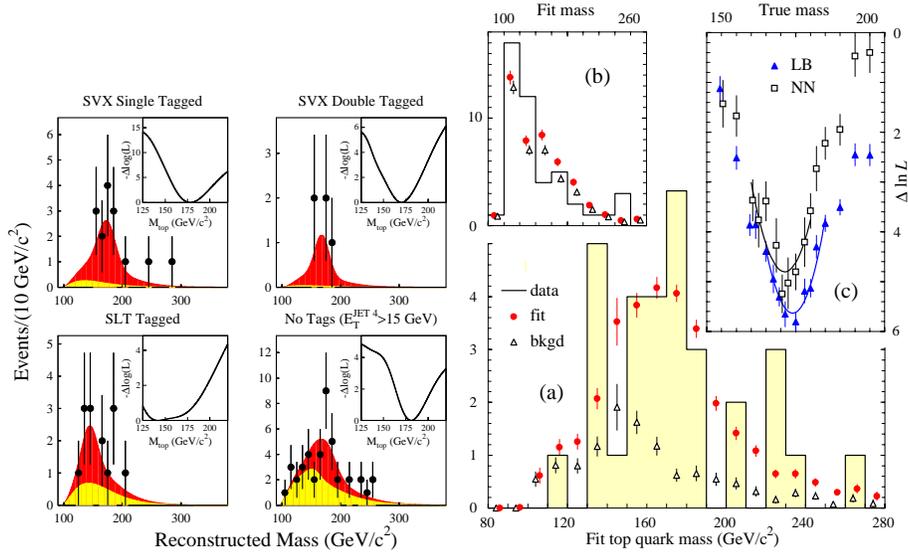


Figure 12. (left) CDF mass fits in the lepton+jet sample. This sample is subdivided in smaller orthogonal samples with different b-tagging features; (right) D0 mass fits in the lepton+jet samples using two types of discriminant to separate signal and background

Table 1. Summary of CDF and D0 measurements of the top quark mass

Experiment	Top event topology			Combined $GeV/c^2$
	di-lepton $GeV/c^2$	lepton+jet $GeV/c^2$	all hadronic $GeV/c^2$	
D0	$168.4 \pm 12.8$	$173.3 \pm 7.8$		$172.1 \pm 7.1$
CDF	$167.4 \pm 11.4$	$175.9 \pm 7.1$	$186.0 \pm 11.5$	$176.0 \pm 6.5$
Combined				$174.3 \pm 5.1$

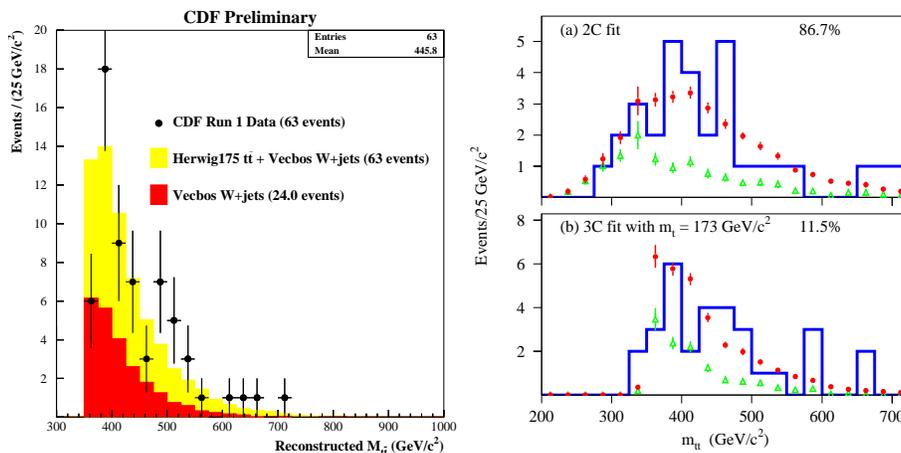


Figure 13. (left) CDF  $M_{t\bar{t}}$  distribution. The mass of each top in the event is constrained to the measured CDF average; (right) D0  $M_{t\bar{t}}$  distribution. The two plots show the distribution with and without constraining the top mass to the D0 average.

Standard Model. Getting a clear signal of single top will be challenging even with the enhanced statistics of the next Tevatron run.

### 3.2 Bottom quark

The physics of the bottom quark has been studied quite extensively at the Tevatron in this and recent years. Beyond the measurement of the production cross sections, which are described in the QCD section, many other b-physics studies have been made. In particular the CDF experiment has exploited in full the large  $b\bar{b}$  cross section available at the Tevatron, thanks to its good magnetic tracking system enhanced with a silicon vertex detector.

In the course of the last year CDF has discovered the  $B_c$  meson <sup>41,42</sup>, using its decay to  $J/\psi l \nu$ . In fig. 14 we show the observed invariant mass distribution of the  $\psi l$  system compared to background expectations. An excess of events is observed with a shape consistent with coming from  $B_c$  decays. A fit to this distribution allows the determination of the meson mass,  $M_{B_c} = 6.4 \pm 0.39 \pm 0.13 GeV/c^2$ . The accuracy of this measurement is limited by the missing neutrino. A more precise

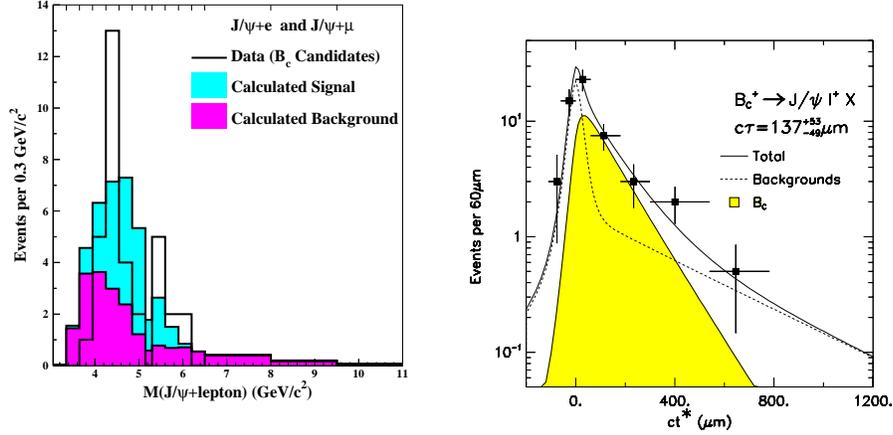


Figure 14. (left) The invariant mass distribution of the  $J\psi e^\pm$  and  $J\psi \mu^\pm$  systems, showing: the CDF data, the calculated background and the expected  $B_c$  signal; (right)  $B_c$  lifetime distribution and fit.

measurement needs fully reconstructed modes which have smaller branching fractions. No unambiguous signal has so far been observed using these decay channels.

Other  $B_c$  parameters have also been measured: the lifetime (fig. 14 right plot) and the production cross section relative to that of  $B^+ \rightarrow J/\psi K^+$ .

All b-hadron triggers at the Tevatron currently involve leptons. This leads to very good limits on rare decays involving electrons and muons <sup>42</sup>.

In table 2 we show the limits set by CDF <sup>42,43</sup> and D0 <sup>42,44</sup> compared to the corresponding results from the CLEO experiment <sup>45</sup> and the Standard Model

Table 2. Summary of branching fraction limits from the Tevatron experiments compared, when available, to the results of CLEO and expectations from the Standard Model.

Process	Branching Fraction Limits						Stand. Mod. expectations
	CDF		D0		CLEO		
	Limit	CL	Limit	CL	Limit	CL	
$B_d^0 \rightarrow K^{*0} \gamma$	$< 2.9 \times 10^{-4}$	95%			$4 \times 10^{-5}$ (observed)		
$B_s^0 \rightarrow \varphi \gamma$	$< 5.7 \times 10^{-4}$	95%					
$B_d^0 \rightarrow \mu^\pm e^\mp$	$< 4.4 \times 10^{-6}$	95%					
$B_s^0 \rightarrow \mu^\pm e^\mp$	$< 2.3 \times 10^{-5}$	95%					
$B_d^0 \rightarrow \mu^+ \mu^-$	$< 8.6 \times 10^{-7}$	95%	$< 4.0 \times 10^{-5}$	90%	$< 5.9 \times 10^{-6}$	90%	$\sim 10^{-10}$
$B_s^0 \rightarrow \mu^+ \mu^-$	$< 2.6 \times 10^{-6}$	95%					$\sim 10^{-9}$
$B_u^+ \rightarrow K^+ \mu^+ \mu^-$	$< 5.4 \times 10^{-6}$	95%			$< 0.9 \times 10^{-5}$	95%	$\sim 2 - 5 \times 10^{-7}$
$B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$	$< 4.1 \times 10^{-6}$	90%			$< 3.1 \times 10^{-5}$	90%	$\sim 2 - 5 \times 10^{-7}$
$B \rightarrow X_s \mu^+ \mu^-$			$< 3.2 \times 10^{-4}$	90%	$< 5.8 \times 10^{-5}$	90%	

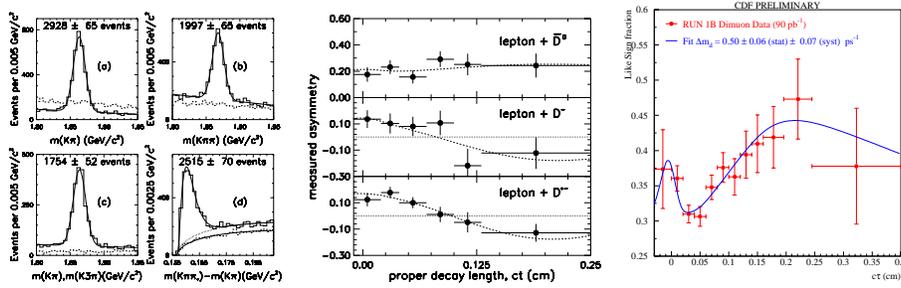


Figure 15. (left) Charm meson signals from B meson semileptonic decay at CDF. The dashed histograms are the distribution of the candidates with the wrong sign correlation; (center) proper time evolution of the mixing asymmetry using semi-inclusive B samples and same side flavor tagging at CDF; (right) proper time evolution of the like-sign fraction in CDF's dimuon sample.

expectations<sup>46</sup> whenever they are available. We notice that for these decay modes the Tevatron results are usually better than CLEO and in some cases are getting close to the sensitivity needed to test the predictions of theory, which are very sensitive to contributions from new physics.

The CDF experiment has collected in the course of run I samples of hundreds of exclusive b-hadron decays in channels containing a  $J/\psi$ , samples of thousands of semi-exclusive decays (i.e. decays into a lepton, a neutrino and a fully reconstructed charmed meson) and even larger inclusive b-enriched samples. The charm signals in the semi-exclusive samples is shown in fig. 15: a signal is observed only when the charmed meson has the charge correlation with the lepton consistent with that of a semileptonic decay of a  $B$  meson.

These datasets have been used in the past years to measure the masses and lifetimes of all known b-hadrons with a precision comparable to, and sometimes better than, CLEO and SLD, and the experiments at LEP.

More recently, several results on  $B_0\bar{B}_0$  mixing have become available from the CDF collaboration. The key to the success of these analyses is the development of techniques to tag the flavor of the  $B_0$ 's at production<sup>47</sup>. These techniques fall into two broad categories: tagging of the flavor of the second b-hadron in the event (opposite side tagging) or tagging the flavor of the  $B_0$  at production exploiting the properties of the b-quark fragmentation into mesons (Same Side Tagging). Examples of opposite side tagging are methods which test the sign of an additional lepton, or attempt to determine the "charge" of a jet by performing a weighed average of the charge of its tracks. These charges are correlated with the sign of the b-quark which gave origin to the lepton or the jet. Same side taggers take the sign of a track kinematically close to the  $B_0$  as a tag of the sign of the b-quark which evolved into the  $B_0$ .

CDF has currently completed several independent analyses of  $B_d\bar{B}_d$  mixing, each using different combination of data set and flavor tagging techniques<sup>47,48,49</sup>; the results from two such analyses are shown in the central and right plot of fig. 15.

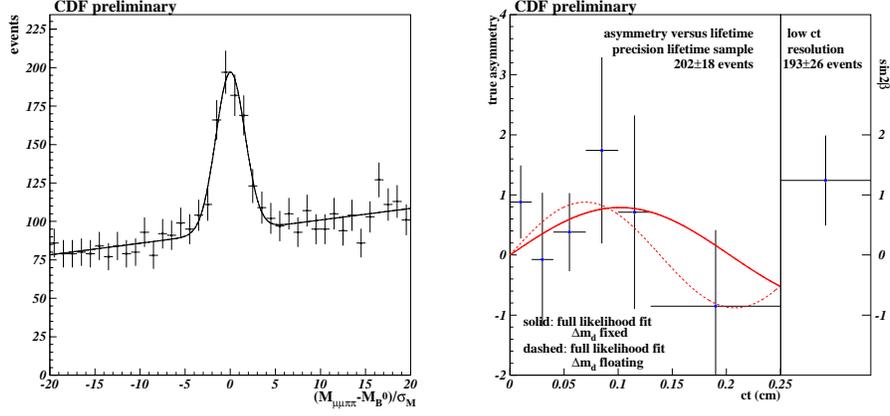


Figure 16. (left) Normalized invariant mass distribution of the  $J/\psi K_S^0$  events; (right) the time evolution of the true CP asymmetry. On the left side is the time-integrated result from data without vertex information.

The CDF average for the  $B_d$  mixing frequency  $\Delta m_d$  is  $0.494 \pm 0.026 \pm 0.026 \text{ ps}^{-1}$ ; in good agreement with the results of the LEP experiments and with similar resolution<sup>49</sup>.

CDF has also set a limit on the  $B_s$  mixing frequency,  $\Delta m_s < 5.8 \text{ ps}^{-1}$  at 95 % CL<sup>50</sup>.

Shortly after this conference CDF has released a new measurement of the CP violating parameter  $\sin(2\beta)$ <sup>49,51</sup>, where  $\beta$  is the phase of the element  $V_{td}$  of the CKM mixing matrix in the Wolfenstein representation. This analysis uses a sample of approximately 400  $B_d \rightarrow J/\psi K_S^0$  decays, as shown in fig. 16, and uses 3 different flavor tagging schemes: lepton, jet charge and same side tagging. The asymmetry between meson and anti-meson production as a function of the proper time is expected to have a sine wave dependence with an amplitude given by the product of the tagging dilution and  $\sin(2\beta)$ . Approximately 50 % of this data does not have vertex detector information and therefore contributes to the measurement only as an integrated asymmetry.

The dilutions of the lepton and jet charge tagging are measured using a parallel sample of  $\sim 1000 B_u \rightarrow J/\psi K^+$ , where we know already the right tagging answer from the sign of the kaon. This method cannot be applied to the same side tagger, since  $B_u$ 's and  $B_d$ 's have different charge correlations with nearby tracks. In this case the dilution is extracted from the mixing analysis using semi-exclusive events and then the results corrected with Monte Carlo to account for the slight difference in momentum spectrum between the  $B_d \rightarrow J/\psi K_S^0$  and the  $B_d \rightarrow l\nu D^{(*)}$ .

After applying a global fit to the data they obtain:  $\sin(2\beta) = 0.79^{+0.41}_{-0.44}$  including systematics. This result corresponds to a unified frequentist confidence interval of  $0 < \sin(2\beta) < 1$  at 93% CL.

Extrapolating from this result the CDF collaboration expects to measure

$\sin(2\beta)$  with an error between 0.05 and 0.1 after collecting  $2 \text{ fb}^{-1}$  of data in the next run of the Tevatron.

#### 4 Conclusions and prospects

Experiments at HERA and at the Tevatron continue their successful study of QCD. The new results confirm an overall agreement with the theory, sometimes even beyond the range where one would expect perturbative QCD to work well, and are constraining more and more our understanding of the proton structure functions. Some high  $Q^2$  excesses still persist, but are still consistent with the Standard Model predictions given the current statistic and systematic errors. The b-sector has an obvious normalization problem; there are however interesting theoretical developments which may lead toward their solution.

The study of phenomena related to rapidity gaps is receiving a growing interest from the Tevatron experiments and attempts are made to link this work with the results of Hera experiments, which have explored this field in depth.

The measurement of the basic top quark parameters has been completed by CDF and D0. While more sophisticated studies of top quark physics have begun, they are very statistics limited and will need the luminosity of the next Tevatron run to deliver relevant results.

The study of bottom quark physics, besides production issues, has been the domain of the CDF experiment, which has produced lately several interesting new results in the area of mixing and CP violation. In particular a new measurement of  $\sin(2\beta)$  with a 0.4 total error has been recently obtained. This proves how the hadron colliders are going to be, in the near future, very competitive in the measurement of the elements of the CKM matrix.

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