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Tests of Perturbative QCD at CDF

E. Buckley-Geer
For the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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Elizabeth Buckley-Geer

Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA

Presented on behalf of the CDF Collaboration

1 Studies of inclusive jet production

1.1 Inclusive Jet Cross-Section

This measurement has very good statistical precision, typically a few percent, with relatively small experimental systematic errors, about 20-40% depending on the jet E_T . The next-to-leading order (NLO) QCD calculations[1] have small theoretical uncertainties due to the choice of renormalization/factorization scale. A measurement of α_s , the strong coupling constant, can be extracted from the inclusive jet measurement. The running of the coupling constant can be demonstrated quite clearly from this single measurement[2]. Finally, we are probing distance scales in the tail of the distribution in the range of 10^{-17} cm. These are the shortest distances available in the laboratory, hence the inclusive jet cross-section is a good place to search for hints of new physics.

The measurement is based on 19.3 pb^{-1} recorded during the 1992-93 collider run. Jets are reconstructed using a cone algorithm with a cone radius $R = 0.7$ where $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ Events were required to pass the following selection criteria

1. $E_T > 15$ GeV and $0.1 < |\eta| < 0.7$
2. At least one reconstructed vertex with $|z| < 60$ cm.
3. Missing E_T significance $S < 6$ ($S \equiv \not\!\!E_T/(\sum E_T)^{1/2}$).
4. No significant energy in the calorimeters that is out-of-time with the proton-antiproton collision.

The data are corrected for detector effects using an unsmearing procedure [3]. The detector effects include energy loss due to uninstrumented regions of the detector and the smearing due to the finite detector resolution. The unsmearing procedure corrects for both types of effects.

The corrected cross-section is shown in Fig. 1 compared to the NLO QCD predictions[1] using MRSD0'[4] parton distributions and a renormalization/factorization scale $\mu = E_T/2$. There is impressive agreement between the data and NLO QCD over seven orders of magnitude. However, the data deviate from the theory predictions for E_T above 200 GeV as can be seen in the linear comparison shown in Fig. 2.

The possible explanations for this deviation include

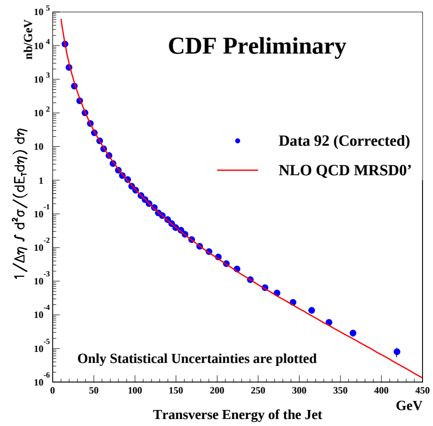

Figure 1: The fully corrected inclusive jet cross-section compared to NLO QCD

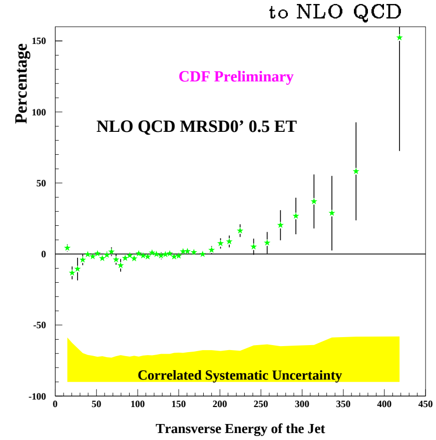

Figure 2: (Data-QCD)/QCD for the fully corrected inclusive jet cross-section

- The choice of renormalization and factorization scale and parton distributions
- Corrections to the NLO QCD predictions, e.g. soft gluon resummation
- Experimental systematics such as jet energy scale
- New physics

The shape of the NLO QCD predictions are essentially independent of the choice of scale, only the normalization is shifted. The predictions using different parton distributions vary by about 30% in normalization but the shape is unchanged. There are currently no calculations of the effect of soft gluon resummation on the inclusive jet cross-section but calculations for the Drell-Yan process at $\tau = M_{ee}/\sqrt{s} = 720/1800 = 0.4$ suggest that the correction is about 10%. The current understanding of the systematic errors suggest that it is difficult to generate such an excess at high E_T . However, studies of the systematics are ongoing. One possible non-standard explanation could be parton substructure. However we would also expect the angular distribution to be modified and we see no evidence for this.

1.2 Two-jet Mass Distribution

The two-jet mass distribution has been measured using 70 pb^{-1} of Run 1A+1B data. The mass is defined using the 4-vectors of the two highest E_T jets in the event. The jets are required to satisfy $|\eta| < 2.0$ and the events are required to have $|\cos\theta^*| < 2/3$. The jets are corrected for the non-uniformity of the detector response but they have not been corrected for the effects of smearing. Instead we compare to a LO QCD shower Monte Carlo (PYTHIA) with a full CDF detector simulation. The QCD prediction is normalized to the data in the mass range 150-300 GeV/c^2. The data are compared to the QCD prediction on a linear scale in Fig. 3. There is a significant excess of events with two-jet mass above 500 GeV/c^2

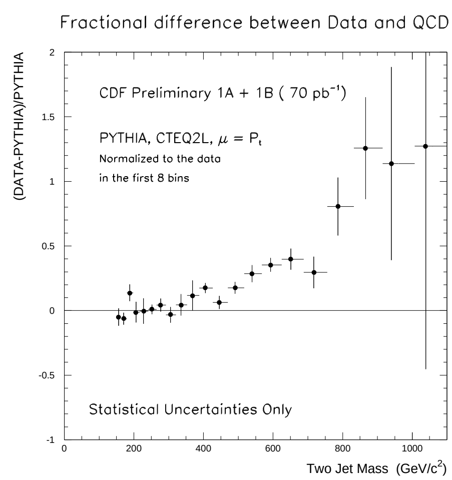

Figure 3: (Data-QCD)/QCD for the two-jet mass distribution

1.3 $\sum E_T$ Cross-section

This measurement uses 19.3 pb^{-1} of Run 1A data. The following selection cuts are applied to the data

1. $\sum E_T > 320$ GeV where the sum is over calorimeter clusters with corrected $E_T > 20$ GeV (jet cone $R = 0.7$).
2. $E_{Tot} < 2000$ GeV.
3. At least one reconstructed vertex with $|z| < 60$ cm.
4. Missing E_T significance $S < 6$ ($S \equiv \not{E}_T/(\sum E_T)^{1/2}$).
5. No significant energy in the calorimeters that is out-of-time with the proton-antiproton collision.

The general properties of this event sample have been shown to be well described by QCD[5]. The data are further corrected for the effects of detector resolution. The NLO QCD prediction[1] is obtained by summing up all the jets in the event that have $E_T > 20$ GeV and $|\eta| < 3.5$. The prediction is normalized to the data in the region 320-480 GeV. Fig. 4 show the comparison on a linear scale. Again we see an excess at large values of $\sum E_T$.

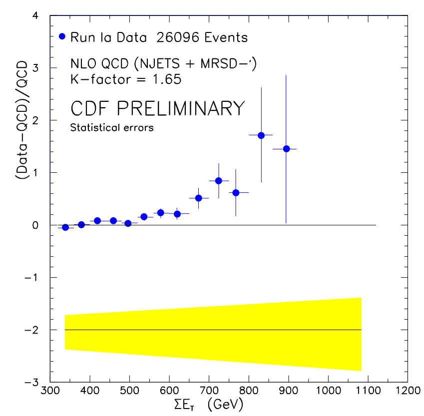

Figure 4: (Data-QCD)/QCD for the fully corrected $\sum E_T$ cross-section

2 Prompt Photon Production

Prompt photon production at the Tevatron Collider is a precision test of Quantum Chromodynamics (QCD) with small statistical and systematic errors. At lowest order the dominant production mechanism is via Compton scattering off a gluon in the initial state. This implies that prompt photons provide a way to study the gluon distribution of the proton.

2.1 Data Sample and Event Selection

The measurement of prompt photons uses the electromagnetic calorimeter which is segmented into towers in $\eta - \phi$ space. The main background is from neutral mesons, π^0, η and K^0_S in jets which are suppressed by requiring that the photon candidate be isolated with less than 2 GeV of energy in a cone of $\Delta R = 0.7$ ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$) around the photon. Additional cuts are applied to obtain the final sample, these are summarized in Table 1.

Table 1: Isolated photon event selection cuts.

Analysis Cut	
EM Energy/Total Energy	> 0.89
Neutral Cluster	No track
Shower profile	Good strip χ^2
Suppress η mesons	Extra strips < 1 GeV
Reject cosmic rays	$\not{E}_T \; / E_T^{\gamma} < 0.8$
Good z-vertex	$\|Z_v\| < 50$ cm
Central photon	$\|\eta\| < 0.9$

2.2 Background subtraction methods

After all cuts the remaining background is predominantly from isolated π^0 and η mesons. Two methods are used to subtract the neutral meson backgrounds. The *profile method* uses the transverse profile at shower maximum in the central strip chambers. The transverse profile of the shower is compared to the profile for a testbeam shower and a χ^2 is extracted. This χ^2 is larger for photons from π^0 and η mesons than for single photons. The *conversion method* uses photon conversions occurring in the magnet coil which are then detected in the preshower detector. The probability of a photon pair from a π^0 or η meson converting is higher than a single photon. The background subtraction is done bin-by-bin.

2.3 Inclusive Photon Results

The differential cross-section is shown in Fig. 5 for the two methods described; in the overlap region they agree to within 5%. The data has a steeper slope that the QCD prediction[6] at low p_T QCD regardless of the choice of parton distribution or renormalization scale. The overall systematic uncertainty is 10% at $p_T = 16$ GeV. The steepening of the data a low p_T does not appear to be explained by including the NLO fragmentation function. Another possible explanation is that additional soft radiation (beyond NLO QCD) contributes at low p_T in the form of K_T. To investigate this effect, a parton shower has been added to the NLO QCD prediction. The effect of this is shown in Fig. 6. The addition of the soft radiation and low p_T steepens the NLO QCD predictions and the agreement with the CDF data is very good.

3 Conclusion

The inclusive jet cross-section measured by CDF is in excellent agreement with NLO QCD below E_T of 200 GeV. Above 200 GeV the measured cross-section begins to deviate from the QCD predictions with an excess of 20-50% in the 260-360 GeV range. A similar excess is observed in the two-jet mass distribution and the $\sum E_T$ cross-section.

The prompt photon cross-section from CDF is in qualatative agreement with next-to-leading order QCD but has a steeper slope at low p_T . Recent studies suggest that addition of soft radiation to NLO QCD may steepen the cross-section at low p_T .

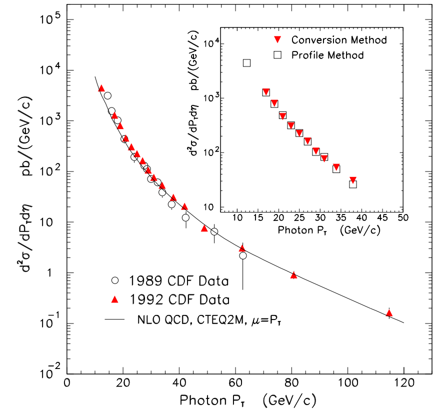

Figure 5: The isolated photon cross-section measured by CDF.

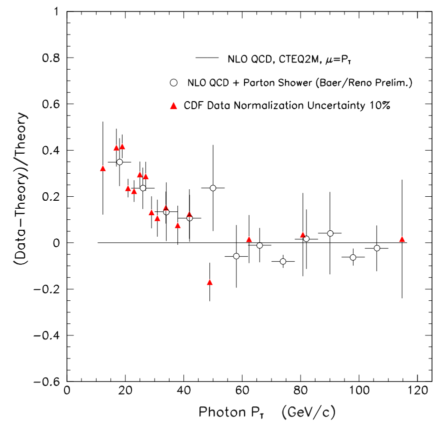

Figure 6: Comparison of CDF data with NLO QCD + parton shower.

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