STATUS OF THE OBSERVED AND PREDICTED $B\bar{B}$ PRODUCTION AT THE TEVATRON

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We review the experimental status of the b-quark production at the Fermilab Tevatron [1]. We compare all available measurements to perturbative QCD predictions (NLO and FONLL) and also to the parton-level cross section evaluated with parton-shower Monte Carlo generators. We examine both the single b cross section and the so called $b\bar{b}$ correlations. The review shows that the experimental situation is quite complicated because the measurements appear to be inconsistent among themselves.

1. Introduction

The bottom quark production at the Fermilab Tevatron has been called one of the few instances in which experimental results appear to challenge the ability of perturbative QCD to accurately predict absolute rates in hadronic collisions. In general, the data are underestimated by the exact next-to-leading-order (NLO) QCD prediction. The most recent measurement from the Tevatron is however in very good agreement with an improved QCD calculation (FONL), and has prompted a number of studies suggesting that the apparent discrepancy has been resolved with incremental improvements of the measurements and predictions.

Because of the experimental difficulty inherent to each result, we review all measurements of the single b cross section performed at the Tevatron, and then compare their average to the standard and to the improved QCD predictions. We also compare the cross sections for producing both b and $\bar{b}$ quarks - centrally and above a given transverse momentum cut - to theoretical predictions.

2. *b*-quark production cross section at the Tevatron

The single b-quark cross section is inferred from the measurement of the production rate as a function of the transverse momentum, p_T, of: B hadrons; or some of their decay products (leptons or ψ mesons); or jets produced by the hadronization of b quarks. Most of the Tevatron measurements correspond to b quarks produced centrally (rapidity $|y^b| \leq 1$) and with $p_T \geq 6$ GeV/c (up to $p_T \simeq 100$ GeV/c). We have performed a consistency check of all available data. For that purpose, we use the value of the single b-quark cross section extracted from the data and integrated from the p_T threshold of each experiment. We determine the ratio R of each measurement to the same theoretical prediction. We then evaluate the average R and its dispersion. As benchmark prediction of the b-quark parton-level cross section we choose the exact NLO calculation implemented with old but consistent sets of parton distribution functions (PDF), since it has been used in most published works, convoluted with the Peterson fragmentation function; B-hadron decay are modeled with the QQ Monte Carlo generator program.

There are 10 measurements of the single b cross section performed by the CDF and DØ collaborations at the Tevatron. The ratios of these measurements to the standard theory are summarized in Table 1.

channel	R for $p_T^{\min}$ (GeV/c) =					
	6	$8-10$	$12-15$	$19-21$	$\simeq 29$	$\simeq 40$
$J/\psi K^+$		$4.0 \pm 15\%$	(3.4)			
$J/\psi K^+$		$2.9 \pm 23\%$	(1.9)			
$\mu\, X$				$2.5 \pm 26\%$	(1.9)	
$e\, X$			$2.4 \pm 27\%$			
eD^0				$2.1 \pm 34\%$		
$J/\psi\, X$		$4.0 \pm 10\%$	(3.4)			
$J/\psi\, X$		$3.1 \pm 9\%$	(2.7)			
$\mu\, X$	$2.1 \pm 27\%$		(1.7)			
$\mu\, X$	$2.5 \pm 25\%$		(3.5)			
b jets (μ)				$2.4 \pm 20\%$		(2.0)

Note: Table 1: Ratio R of measured single b cross sections to a prediction based on the exact NLO calculation .

Using the measurements listed in Table 1, we derive an average ratio of the data to the standard theory that is $< R >= 2.8$; the RMS deviation of the 10 measurements in Table 1 is 0.7

The NLO prediction strong dependance on the choice of the factorization and normalization scales is generally taken as a symptom of large higher-order corrections. A new calculation, that includes the resummation of the logarithms of (p_T/m_b) corrections with next-to-leading logarithmic accuracy (NLL) and the matching with the fixed-order NLO calculation (FONLL), convoluted with a new set of consistent fragmentation functions derived using LEP data, predicts a ratio of the average single b cross section measured at the Tevatron of approximately 1.5.

Exact NLO predictions do not easily allow the full simulation of events produced at the Tevatron. Therefore, studies that involve b-quark production such as top quark studies or searches for new physics, make use of parton-shower Monte Carlo programs that use the leading-log (LL) approximation. The parton-level cross section estimated with LL generators is approximately a factor of two larger than the exact NLO prediction because the contribution of terms of order higher than α_s^2 is a factor of two larger than the contribution of α_s^3 terms estimated with the exact NLO calculation and model correctly the measured single b cross section.

Leading-order (LO) and higher-than-LO terms are sources of b and $\bar{b}$ quarks with quite different topological structure. The production of events with both a b and $\bar{b}$ quark with $p_T \geq 6$ GeV/c and $|y| \leq 1$ is dominated by LO diagrams and the parton-level cross sections predicted by the exact NLO calculation is comparable to that predicted by LL Monte Carlo generators.

The cross section for producing both b and $\bar{b}$ quarks centrally and above a given p_T threshold, $\sigma_{b\bar{b}}$ or $b\bar{b}$ correlation, is dominated by LO terms, and the LL and NLO predictions are quite close

R_{2b}, the ratio of $\sigma_{b\bar{b}}$ measured at the Tevatron to the exact NLO prediction, $\simeq 1$ would imply that the parton-level cross section predicted by LL generators (NLO) is correct and that the contribution of higher-than-LO terms has to be a factor of two larger than in the present NLO or FONLL prediction. If the ratio R_{2b} is much larger than one, then the agreement between the observed single b cross section and the prediction of LL Monte Carlo generators is fortuitous and agreement with the data may be found by using harder fragmentation functions as in the FONLL calculation.

We review five measurements, listed in Table 2, and derive a value of $< R_{2b} >= 1.8$ with a 0.8 RMS deviation. Such a large RMS deviation indicates that the experimental results are inconsistent among themselves. Additional measurements are certainly needed to clarify the experimental situation. Discrepancies between data and the NLO prediction of $\sigma_{b\bar{b}}$ are observed when identifying b quarks through their semileptonic decay into muons. The present discrepancies are reduced if the rate of observed semileptonic decays is approximately 50% higher than what is expected.

channel	R_{2b} for $p_T^{\min}$ (GeV/c) =			
	$6-7$	10	15	$\simeq 20$
$b+\bar{b}$ jets			$1.2 \pm 25\%$	
$b+\bar{b}$ jets				$1.0 \pm 32\%$
$\mu + b$ jet		$1.5 \pm 10\%$		
$\mu^+ + \mu^-$	$3.0 \pm 20\%$			
$\mu^+ + \mu^-$	$2.3 \pm 33\%$			

Note: Table 2: Ratio R_{2b} of $\sigma_{b\bar{b}}$, the observed cross section for producing both b and $\bar{b}$ quarks, centrally and above a given $p_T^{\min}$ threshold, to the exact NLO prediction.

3. Conclusions

We review all measurements of the single b cross section performed at the Tevatron and compare them to an exact NLO perturbative QCD prediction, that uses pre-HERA sets of parton distribution functions and the Peterson fragmentation function. The average ratio of the data to the NLO prediction is $< R >= 2.8$ with a 0.7 RMS deviation much larger than the quoted measurement uncertainties indicates that experimental results are inconsistent among themselves.

The average of the data is found to be in agreement with the parton-level cross section evaluated with parton-shower Monte Carlo generators and is within the range of uncertainty of the FONLL prediction that in turn is 90% higher than the NLO prediction, due to harder than Peterson fragmentation functions. The contribution of higher-than-LO terms returned by LL Monte Carlo generators is approximately a factor of two larger than that in the FONLL or NLO calculations.

The ratio of the $\sigma_{b\bar{b}}$ measurements (the cross section for producing both b and $\bar{b}$ quarks centrally and above the same p_T threshold) to the NLO prediction is $< R_{2b} >= 1.8$ with a 0.8 RMS deviation, and suggests that these measurements are also inconsistent among themselves. The $< R_{2b} >$ value supports the FONLL approach. However, the level of agreement between data and theory appears to be a function of the number of semileptonic decays used to identify b quarks.

References

1. F. Happacher*et al.,* Phys. Rev. D **73**, 014025 (2006).