Bottom Production Cross Section at FNAL Energies

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Since experimental data on the hadroproduction of bottom is almost non-existent, we must rely on theory for guidance. Two recent papers [1,2] have addressed the calculation of the b-quark cross-section in the energy regions accessible to the Fermilab collider and the Fermilab external beam. Reference 2, in particular, summarizes the status of the theoretical predictions. In this note, I briefly review the remarks of reference 2 on the state of the theory, then make an assessment from an experimenter's point of view on the reliability of the predictions, and finally propose a set of "standard cross-sections" for the total bottom cross-section, σbb, for use in this workshop. The "standard" purports only to assist in the relative evaluation of rates for different energies and incident particles. By using the "standard", we can avoid large apparent differences in various approaches due to choice of model.

I. Review of Status of QCD Calculation of Bottom Production

The calculations presented in ref 1,2 include contributions of QCD processes of order α_s^2 and are therefore "Born" approximations. The limitations and uncertainties of this approximation are stated in reference 2 to be the following:

A. It is not clear to what extent "perturbative" or short-range QCD processes dominate over "non-perturbative" QCD processes. Perturbative QCD to order α_s^2 badly underestimates the measured cross-section for charm hadroproduction. The reason is believed to be the presence of large "non-perturbative" contributions. Berger argues in reference 2 that the bottom quark mass is sufficiently large that perturbative effects should dominate. He observes that perturbative QCD begins to give good results for Jet hadroproduction at a transverse momentum scale of 5 GeV/c which is the same size roughly as the b-quark mass. However, in light of the experience with charm, it is probably not impossible for there to be "some" non-perturbative contributions.

B. There are non-negligible contributions from diagrams proportional to α_s^3 and higher orders. These have not yet been completely calculated so their size can only be estimated. For some kinematic regions, and topolonies these diagrams actually dominate the α_s^2 contributions but those regions contribute only negligibly to the total b-quark cross-section. These diagrams also contribute to other processes such as Drell-Yan dilepton production. There they are believed to produce the famous "K-factor" whose value is somewhat larger than 2. Berger argues that this should also be the order of the higher order contributions to σ_b but of course this remains speculation and

therefore creates uncertainty in the prediction until the calculations are more complete.

C. There is uncertainty over the value to use for the b-quark mass and the total cross-section is quite sensitive to this choice. A variation from 4.6GeV/c^2 to 5.4GeV/c^2 changes the α_s^2 contribution by a factor of 4 and dramatically affects the threshold behhavior of bottom-production.

D. There is uncertainty of the choice of the QCD evolution scale, Q^2. This scale appears both in the evaluation of $\alpha_s(Q^2)$ and in the computaion of the (evolved) quark, anti-quark, and gluon structure functions. The overall effect of this scale is complicated and depends on the X-region "sampled" by the process under consideration. Choices include $Q^2 = m_b^2$, $4m_b^2$ and s (the total energy squared in the parton-parton center of mass). Different choices can make large differences, factors of 2 to 4, in the result.

E. There are the usual differences arising from use of different parameterizations of the gluon, quark and anti-quark structure functions. This is not so severe in the kinematic regions accessible to the FNAL Collider and Fixed Target programs since they "sample" x values ($x \sim M_b/\sqrt{s}$) where at least the quark and anti-quark structure functions are well-measured and where all parmaterizations must therefore agree. Various choices seem to produce results within 15% of each other.

II. An Experimenter's (me) Assessment of the Situation

Based on reference 2, the actual variations one might expect among models of b-quark production are ~ a factor of 8 coming from just the freedom in the choice of parameters for the α_s^2 calculations and an additional factor of 2-4 from various guesses as to the contributions omitted from the α_s^2 calculations. I conclude that the theory should be trusted to give the cross-section to within an order of magnitude, but certainly is <u>not</u> good to a factor of two. The "freedom" or "uncertainty" in the α_s^2 part of the calculation is shown in Table I.

Table I: σ (pp bbx) from reference 2
A. Evolution Scale $Q^2=m_b^2$

	Plab		
M_b	300 GeV	600 GeV	900 GeV
4.6 GeV	0.54 nb	8.20 nb	25.6 nb
5.0 GeV	0.17 nb	3.51 nb	12.4 nb
5.4 GeV	0.05 nb	1.52 nb	6. nb

B. Evolution Scale Q^2=s

M_b	300 GeV	600 GeV	900 GeV
4.6	0.16 nb	2.51 nb	8.19 nb
5.0	0.05 nb	1.09 nb	3.99 nb
5.4	0.016 nb	0.48 nb	1.98 nb

Values for m_b =5.0 and Q^2 scale = $4m_b^2$ are given in figure 13 of reference 2 and for m_b from 4.7 to 5.3 with Q^2 scale = 4 m_b^2 in Fig. 27 of reference 1.

III. Some "Standard" Cross-sections

Lacking additional theoretical or experimental guidance, it seems "reasonable" to use m_b = 5.0 GeV and a Q^2 scale of $4m_b^2$. This produces cross-sections which are neither wildly optimistic nor unduly pessimistic. The proposed " standard" values are

σ pp bbx

400	.2nb
600	1.0
800	3.0nb

σ πp bbx

400	2
600	5.0
800	10nb

σ pp bbx ($\sqrt{s}$=2 TeV)

~10-20μb

References:

1. R.K. Ellis, C. Quigg, Fermilab Pub,FN-445, A Pinacoteca of Cross Sections for Hadroproduction of Heavy Quarks, Jan 1987.
2. E.L. Berger, Heavy Quark Production in Hadron Collisions, ANL-HEP-CP-87-53, June 1987.