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Photo- and Hadro- Production of Charm and Beauty at Fermilab

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PHOTO- AND HADRO- PRODUCTION OF CHARM AND BEAUTY AT FERMILAB

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The photoproduction of Charm with experiment E687 and the collider hadroproduction of Beauty with the CDF and DØ detectors are briefly reviewed. Measurements are confronted with QCD calculations.

1 Introduction

This report concentrates on results from three Fermilab experiments: the photoproduction of charm in the fixed target mode from experiment E687, and the collider hadroproduction of b-quarks and B-mesons as measured respectively by the DØ and CDF detectors. Only the production of open flavors is considered. For heavy quarkonia results see the contribution from B. Naroska to these proceedings.

2 Photoproduction of Charm

E687 results are from the 1990-91 Tevatron fixed target run. An extracted photon beam of average energy 200GeV impinges on a Berillium target. The total cross section for charm photoproduction under these conditions is around one microbarn, and about half of a percent of all inelastic events do have charm production. Over 80k charm hadrons have been fully reconstructed. At this energy scale, the manifestation of a resolved photon component (dissossiation into hadrons) is largely negligible, and difficulties associated with an unknown photon structure function are avoided. The photon is dominantly a point particle probe, and the dynamics of photoproduction[1] is rather simpler than that of hadroproduction.

Among the E687 measurements, two of particular relevance for testing models of photoproduction are the single inclusive ${p_T}^2$ distributions of charm hadrons[2], and the fully exclusive $D\overline{D}$ correlations[3]. Figure 1 shows the observed ${p_T}^2$ spectrum for the D^+ in the channel $K^-\pi^+\pi^+$. Also shown (solid line histogram) is the NLO-QCD calculation [4] for photoproduced charm *quarks*. As expected, the predicted quark spectrum is harder than that of the observed mesons, since fragmentation necessarily softens the meson spectrum. A similar plot for the Λ_c in the $pK\pi$ channel (not shown here) features the same effect, this time significantly less accentuated, again in line with expectations since a heavier hadron needs a higher fraction of its parent quark momentum.

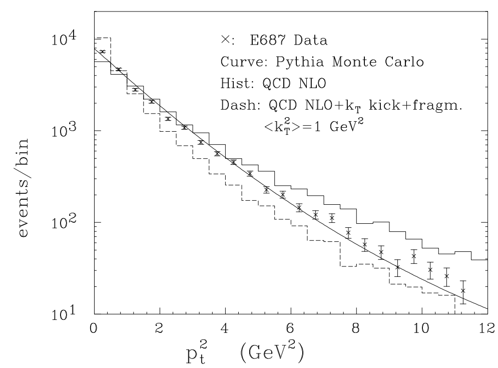

Figure 1: ${p_T}^2$ spectrum for the $D^+ \to K^-\pi^+\pi^+$

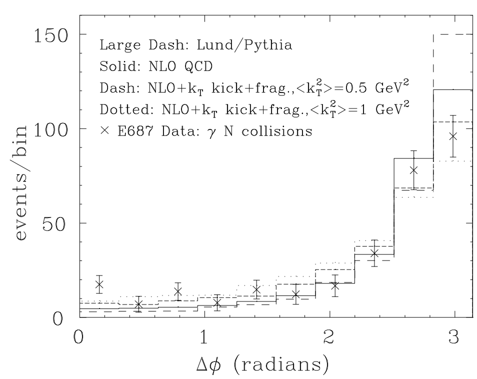

Figure 2: $\Delta\phi$ spectrum for the $D\overline{D}$pair

To investigate non perturbative effects, the QCD calculation was augmented[5] by Peterson fragmentation[6] plus the addition of an intrinsic transverse momentum (k_t) to the incoming parton. The latter is motivated by the fact that fragmentation alone overshoots the softness of the observed mesons as indicated in figure 1, and good agreement is achieved only for a relatively high $< {k_t}^2 >$ of around $2GeV^2$.

E687 was able to isolate 325 ± 23 events in which $D\overline{D}$ pairs were fully reconstructed. Production correlations such as the acoplanarity angle $\Delta\phi$ between the two mesons in the plane transverse to the incident photon were studied. The resulting spectrum is shown in figure 2. Leading order production models necessarily induce strict azimuthal symmetry between the produced quarks, implying a sharply peaked $\Delta\phi$ distribution at π radians. While NLO-QCD corrections[4] considerably broaden the predicted $\Delta\phi$ spectrum, E687 observes[3] an even broader distribution, and again fragmentation and an intrinsic (k_t) kick must be called in for improved agreement. This time the suggested $< {k_t}^2 >$ input is around $1GeV^2$.

3 Collider Hadroproduction of Beauty

The total production cross section for central $b\bar{b}$ pairs (say rapidities out to 1) at the Tevatron collider is of the order of 30 microbarns which, at the current luminosities of $10^{31}cm^{-2}s^{-1}$ implies pair production at rates around $300H_z$. Still, backgrounds can be severe since the ratio of this cross section to the total inelastic one is $O(10^{-3})$. Efficient triggering strategies are vital if one is to make good use of the abundant production rates. At trigger (fast recognition) level, the most helpful teltales of heavy flavor production are the high transverse momentum leptons from beauty/charm semileptonic decays, and also dileptons from the decays of heavy quarkonia. Both experiments at the Tevatron collider, CDF and DØ, reap their heavy flavor physics from triggers that rely heavily on muon (less often electron) recognition.

The next two sections are dedicated respectively to DØ and CDF recent b-production measurements. Results are from the 1992-93 Tevatron run, when DØ was inaugurated and CDF was fit with a silicon vertex detector (for downstream secondary decay vertex detection), a most powerful tool for b-physics. For consistency checks two independent measurements are presented for each experiment. Results from DØ are for b-quark production cross sections, whereas those from CDF are for B-mesons. Both experiments have other independent beauty production results that are not featured here.

4 b-Quark Production at DØ

The b-quark (single particle inclusive) integrated cross section as a function of minimum p_T has been extracted from several independent data samples, and reported here are those from inclusive muons[7] and inclusive non-isolated dimuons[8]. All methods have shown very good consistency with one another, as can be seen from figure 3 where results from the inclusive J/Ψ sample are also featured.

For the inclusive muon sample $75nb^{-1}$ of data were collected in some 20 hours of dedicated runs for the single muon trigger. The dimuon sample comes from $6.6pb^{-1}$ of dimuon triggers. Offline, muon track selection criteria are very strict, with clear signals and good track matches at all stages of detection, central tracker, calorimeter deposition, and no missing muon modules. Only tracks of rapidity less than 0.8 and p_T greater than $4GeV/c$ were retained, and for the dimuon sample two additional cuts were imposed. A dimuon invariant mass between 6 and $35GeV/c^2$ very effectively rejects J/Ψ and Z decays, whereas a requirement that every muon should be non-isolated (inside a jet) rejects Υ decays and cosmic ray contamination. Only 197 high purity dimuons survived this selection, while the final number of events in the single muon sample was around 16k.

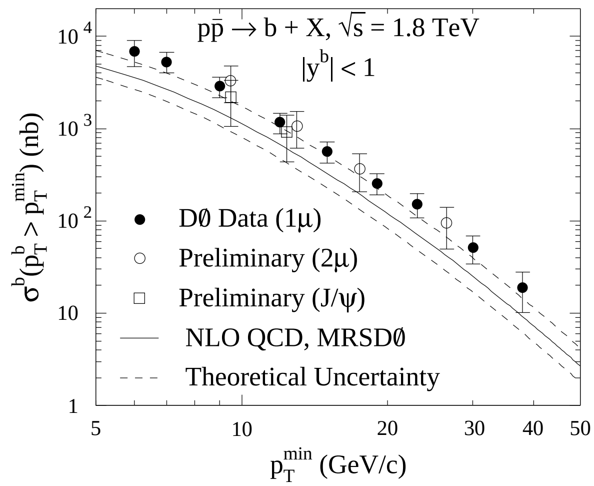

Figure 3: b-Quark Production at DØ

The high mass of the b-quark gives its semileptonic decay muon a very distinct transverse momentum p_T^{rel} with respect to the accompanying jet. For each sample, the fraction of events with b-quark production is extracted from a p_T^{rel} analysis where typical distributions from different physics origins are modelled by Monte Carlo. Model dependence is also present as the parent quark kinematics is accessed from that of the daughter muons. These two procedures are the most severe contributors to the total systematic errors estimated around 25–30% . The resulting b-quark cross sections are plotted in figure 3 against NLO-QCD calculations[9]. The theoretical prediction (full line) is based on use of MRSDO structure functions with $\Lambda_5^{\overline{MS}} = 140$ MeV, and $m_b = 4.75$ GeV/c^2. The theoretical uncertainty (dashed lines) results from choosing $100 < \Lambda_5^{\overline{MS}} < 187$ MeV, and the factorization-renormalization scale μ in the range $\mu_0/2 < \mu < 2\mu_0$, where $\mu_0 = \sqrt{m_b^2 + \langle p_T^b \rangle^2}$. It can be seen that there is very good shape agreement between measurement and theory, but data do suggest a higher normalization.

5 B-Meson Production at CDF

Earlier measurements by CDF (from the 1988-89 run) of the integrated b-quark production cross section were extracted from the inclusive semileptonic[10,11] and J/Ψ[12] samples. Since then, the addition of extra muon chambers behind shielding plates, and of the silicon vertex detector (SVX) has considerably enhanced CDF's b-physics capabilities. With an improved ability to reconstruct B mesons, systematic uncertainties in background subtraction as well as the model dependence of the measurements have been dramatically reduced.

CDF has recently measured the B meson differential cross section using two rather different and complementary techniques whose results are plotted in figure 4. The first[13] and most accurate of these is based on a complete reconstruction of the hadronic final states in the channels $B^+ \to J/\Psi\ K^+$ and $B^o \to J/\Psi\ K^{*o}(\to K^+\pi^-)$ $(+\ c\ c)$ Data were collected from $19pb^{-1}$ of dimuon triggers, with an offline dimuon selection of invariant mass within $\pm 300 MeV/c^2$ of the J/Ψ mass, and subject to p_T lower limits of 2 and 3 GeV for the individual muons. For resonance finding, track combinations were constrained to a common secondary vertex in the SVX, with B candidates satisfying $p_T > 6GeV$ and $c\tau > 100\mu m$. A counting experiment was performed over the B p_T bins of $6-9-12-15GeV$, and the cross section extracted after the appropriate corrections for acceptance, efficiencies, branching ratios and integrated luminosity.

The second method[14] entails a partial reconstruction of semileptonic final states. Data was collected from $18pb^{-1}$ of single muon triggers, and the general strategy is to reconstruct charmed D mesons in association with a muon. The B mesons are then recovered from their inclusive semileptonic final states

$B^- \to D^{(*)o}\ \mu^-\ X \quad (D^o \to K^-\ \pi^+)\ (+\ c\ c)$

$\overline{B}^o \to D^{(*)+}\ \mu^-\ X \quad (D^{*+} \to D^o\ \pi^+)\ (+\ c\ c)$

Offline, only muons of p_T above $7.5GeV$ were retained, and non-muon tracks which form with the muon an invariant mass smaller than $5.3GeV/c^2$ (the B mass) were kept for the resonance combinatoric search. This technique naturally yields larger samples than the first, and covered the higher B p_T range of 18 to 34 GeV. For complete systematic independence of the previous method, this search was not SVX constrained. However, due to undetected particles in the inclusive final states, the B meson p_T is not directly measurable and was obtained from the partially detected final state kinematics by Monte Carlo modelling of the complete event. Uncertainty in meson momentum was estimated around 15% . As before, a counting experiment is performed over the p_T bins of 18-22-26-34GeV. For both methods, the B^{+-} and B^ocross sections were assumed identical.

The matching between the p_T ranges covered by each method in figure 4 attests the consistency between both

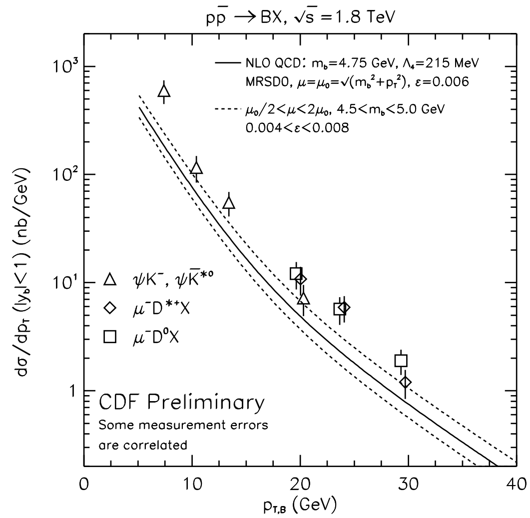

Figure 4: B-Meson Production at CDF

measurements which again agree in shape with the NLO-QCD prediction and suggest a higher normalization.

6 Conclusion

Measurements in the photoproduction of charm and collider hadroproduction of beauty were confronted with next to leading order QCD calculations. In the photoproduction case, a significant amount of non perturbative inspired modelling must be brought in so that theory matches data. Hadroproduction measurements agree in shape with the QCD theory over many orders of magnitude, whereas in absolute normalization the data are about a factor of two above the central value predictions.

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