Heavy flavor production in CDF

Mario Campanelli

DPNC University of Geneva

Abstract. In this paper we report on several results about heavy flavor production at the CDF experiment at Tevatron. For trigger reasons, heavy flavor production is classified in low-and high-pt physics, and different experimental approaches are followed in the two cases. While at low-pt it is possible thanks to the large statistics to perform exclusive reconstruction of the final state, at higher pt particles create hadronic jets and heavy flavors are identified from reconstruction of a secondary vertex with high invariant mass.

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INTRODUCTION: WHY STUDYING HEAVY FLAVORS AT HADRON COLLIDERS

Hadron colliders are an hostile environment for studying complex events like those originating from heavy flavor decays. Dedicated accelerators and experiments have been built for this purpose, to fully reconstruct b- and c-hadrons in a clean e^+e^- environment. In hadron colliders life is more difficult, but it is possible to profit from the large cross section and luminosity that for the Tevatron parameters yields a rate for b of a few KHz and much larger for charm. The study of b production is an interesting problem in itself for perturbative QCD. Since the b mass is larger than the QCD scale, perturbative expansion is expected to work quite well in this case. State of the art calculations go above next-to leading order and include re-summed first-order next-to-leading logarithms. New fragmentation functions taken from LEP data have significantly changed the theory predictions for b production cross section in the central region over the last years.

EXPERIMENTAL TECHNIQUES

Tevatron and CDF

Tevatron is the highest-energy particle accelerator in the world. After the upgrade, this machine is able to collide proton and anti-proton beams of 0.98 TeV each, with a peak luminosity so far of $1.2 \times 10^{32} cm^{-2} s^{-1}$. So far, over 1 fb^{-1} has been delivered to the experiments, and the expectations are for a final luminosity between 4 and 8 fb^{-1} before the start of LHC. The analyses described here are performed using an integrated luminosity between 60 and 400 pb^{-1}.

The CDF detector has been fully upgraded for the run II of the machine. In particular, modifications involved a completely new inner silicon tracker (SVX II and ISL), a new tracking chamber (COT), similar to the previous one but much faster, an extended calorimetry range that allowed good electromagnetic calorimetry also in the end-cap region, a revolutionary device allowing on-line tracking (SVT) that can be used at trigger Level 2 to select tracks with large impact parameter, and finally a completely revised trigger and data acquisition system, that allowed the detector to cope with the much increased bunch crossing rate. Detector parameters relevant to the measurements presented in this paper are the resolution for electromagnetic showers of $13.4\%/\sqrt{E_T} \oplus 2\%$ and for hadronic showers of $75\%/\sqrt{E_T} \oplus 3\%$, a track pt resolution of $\sigma(pt)/pt = 0.15\% pt$ and an impact parameter resolution for tracks of 40 μm, including 30 μm coming from the beam spread.

Triggering and tagging

Even if large in absolute terms, heavy flavor production is anyway much smaller than ordinary QCD- a 3 or 4 orders of magnitude in the case of b production. To study heavy flavors, first we have to collect them, IE be able to trigger on those particles. At high p_t, we have unbiased triggers that record all events with hadronic jets with a transverse energy above a certain threshold (20, 50, 70 and 100 GeV). Since especially at low threshold the production rate largely overcomes the storing capacity of the data acquisition system, large prescale factors are applied. Jets containing heavy flavors are then identified off-line, reconstructing the secondary vertex originating from the decay of the heavy flavor. At low p_t QCD production is so high that the trigger prescale factors should be enormous and no relevant physics could be performed with those samples. In Run I heavy-flavor enriched samples were produced tagging on the presence of leptons with high p_t with respect to the jet axis, an indication of semileptonic decays of b and c quarks. In Run II, the Silicon Vertex Tracker (SVT) allows on-line measurement of track parameters, including the impact parameter, indication of a delayed decay of an heavy flavor. The SVT works in conjunction with the eXtremely Fast Tracker (XFT), that measures the p_T and ϕ of tracks in the central chamber. The SVT identifies hits in the silicon, and builds “roads” of possible track candidates. Then the hits are fed into an associative memory where thousands of possible hit configurations are stored, together with the associated track parameters. This method is needed since no fit of the hits can be performed within the time limits (13 μs) imposed by the trigger; this procedure gives anyway very competitive performances, resulting in an impact parameter resolution of 47 μm. Thanks to this device, it is now possible to have high-statistics samples of hadronic heavy flavor decays.

CHARM PRODUCTION

One of the first measurements that used the SVT capabilities was the cross section of exclusively reconstructed charm states: $D^0 \to K\pi$, $D^* \to D^0\pi$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to \phi\pi^+$. The analysis has been carried on with 5.8 ± 0.3 pb^{-1}1 of data, collected

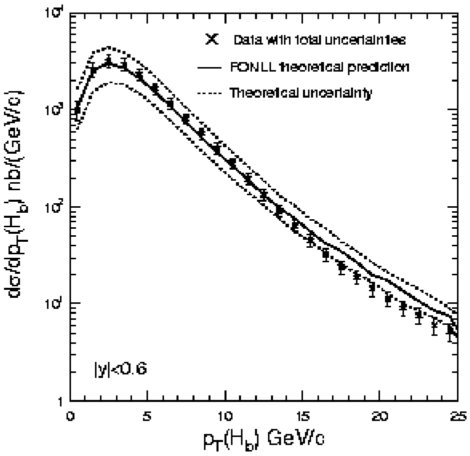

FIGURE 1. b production cross section from exclusively-reconstructed J/Ψ decays

during the first months of Run II data taking. Events originated from prompt charm or from b decays have been distinguished fitting the distribution of the impact parameter of the fully reconstructed system. This allowed to extract direct charm fractions for the four cases: $86.4 \pm 0.4 \pm 3.5\%$ for D^0, $88.1 \pm 1.1 \pm 3.9\%$ for D^{*+}, $89.1 \pm 0.4 \pm 2.8\%$ for D^+ and $77.3 \pm 3.3 \pm 2.1$ for the D_s^+. The measured differential cross section is in good agreement with theory predictions [1], even if on the upper side of the theory error band.

SPECTROSCOPY WITH SVT DATASETS

Given the large dataset from the SVT, many channels have been studied, and CDF has the largest world sample for many exclusive channels, especially those involving heavy states like B_s, Λ_B, D^{**}, etc. CDF was also the first experiment to confirm the claim [2] from the Belle collaboration of the existence of a new resonance, so far known as X(3872), decaying into $J/\Psi\pi^+\pi^-$. The first evidence reported an excess of 730 candidates, with a mass of $3871.3 \pm 0.7 \pm 0.4$ MeV, and a width of 4.9 ± 0.7 MeV, consistent with detector resolution. X significance over background is enhanced by requiring high mass of the dipion system and this, together with an helicity analysis under investigation, is expected to shed more light on the real nature of this state.

B PRODUCTION IN J/ψ

This analysis is not using a dataset based on the SVT trigger, but on a trigger that requires two muons of 2 GeV p_t. Since the muons can also be back-to-back, the total p_t of the system can go to zero. The analysis aims to select events with J/Ψ production, and as in the case of exclusive D decays, distinguish those from J/Ψ to those coming from b decays. Opposite to the previous case, now we are interested in the secondary production; in order to do that, in every J/Ψ p_t bin the distribution of the variable

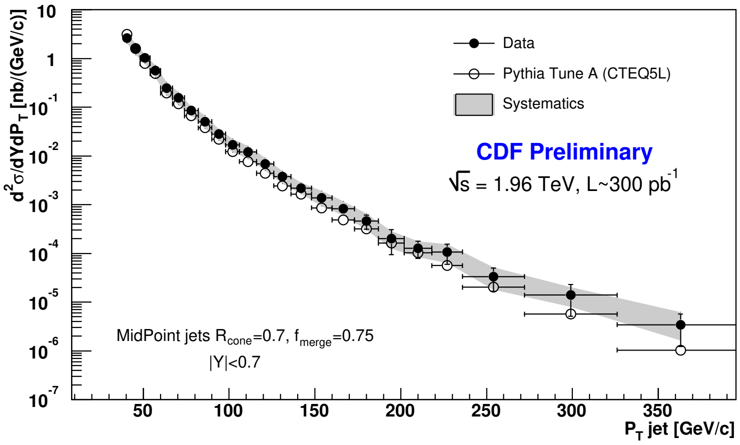

FIGURE 2. Differential cross section for b jets

$L_{xy}/p_t(J/\Psi)/M(J/\Psi)$ is fitted to get the components of prompt, b decays and background. The total b cross section is obtained de-convoluting the J/Psi branching ratio from the b fraction, and is shown in figure 1.

INCLUSIVE B-JET PRODUCTION

The measurements presented in the next two sections do not deal with exclusively reconstructed final states, but with hadronic jets. As already mentioned, in this case the heavy flavor production is identified from the presence of a secondary decay vertex in the event. The efficiency of this "b-tagging" algorithm is about 40%, and depends on p_t; it has been studied from Monte Carlo and cross-checked using b-enhanced samples containing isolated leptons. To merge particles in jets, CDF used during Run I the JetClu algorithm, a cone algorithm based on preclustering and including in a jet all particles inside a cone in $\eta - \phi$. This algorithm present some difficulties and was replaced in Run II analyses by Midpoint, infrared and collinear safe, that adds intermediate points to the original seeds, curing "pathological" cases often encountered by JetClu. After jets are formed and a secondary vertex is found, we still have to determine the fraction of b quarks present in our sample. In fact the tagging algorithm is not only selecting b quarks, but also charm and light quarks. The b fraction is estimated for every p_t bin making a distribution of the reconstructed invariant mass of the secondary vertex, and fitting it using templates coming from MonteCarlo for b and c+light jets. b-fractions estimated this way range from 40 to 15% of the total tagged sample.

Finally, the differential inclusive b-jet cross section is shown in figure 2, compared to leading-order (Pythia) MonteCarlo. The ratio between data and Pythia is about 1.4, giving an estimate of the relevance of higher orders in this measurements.

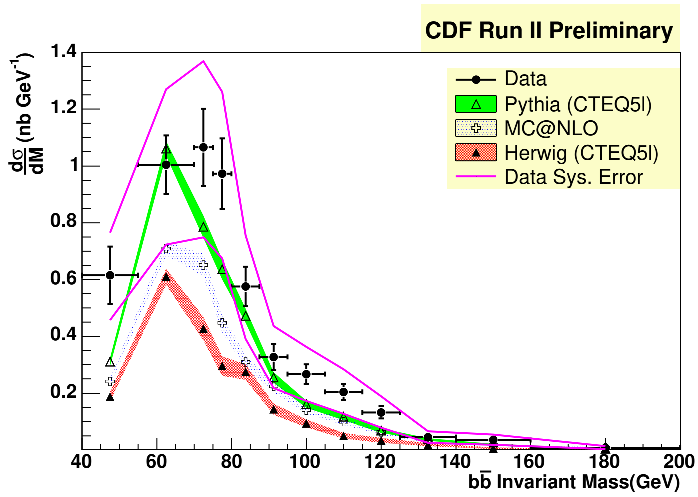

FIGURE 3. Invariant mass of the $b-\bar{b}$ system

PRODUCTION OF B-JET PAIRS

A similar analysis has been carried on to measure production of $b-\bar{b}$ jets. The requirement in this case is to have two tagged jets in the central region ($|\eta| < 1.2$), and also in this case the invariant mass of the secondary vertex is used to determine the b content of the tagged jets. The measured $b-\bar{b}$ invariant mass is shown in figure 3, compared with two leading-order and one next-to-leading order MonteCarlo codes. We see that the agreement with the next-to-leading order code is not better than Pythia, and this is probably due to the fact that the latter gives a better description of the underlying event, absent from the next-to-leading order code.

ASSOCIATED PRODUCTION OF HEAVY FLAVORS AND PHOTONS

Measuring production of b and associated with a photon is important for supersymmmetry searches, and to measure the b and c proton Pdf's. Photon production in an hadron collider is overwhelmed by a large background due to π^0 decays in $\gamma\gamma$; it is possible to distinguish the two by looking at the shape of the signal in the preshower detector in front of the calorimeter, or in the CES, a wire chamber located inside the calorimeter at the position of the maximum of the shower. It is however not possible to perform an event-by-event separation of signal and background, so only a distinction on a statistical basis is possible. Weights are given to each event according to its probability of being a real photon, and then statistical errors are properly treated to account to account for the unavoidable inclusion of background events. Also in this case the secondary vertex mass is used to identify the quark type, but instead of just separating the b from the rest, in this case a fit to three distributions, for b- c- and light-quarks is performed, to separately measure cross sections for b+γ and c+γ. Cross sections as a function of photon E_t are

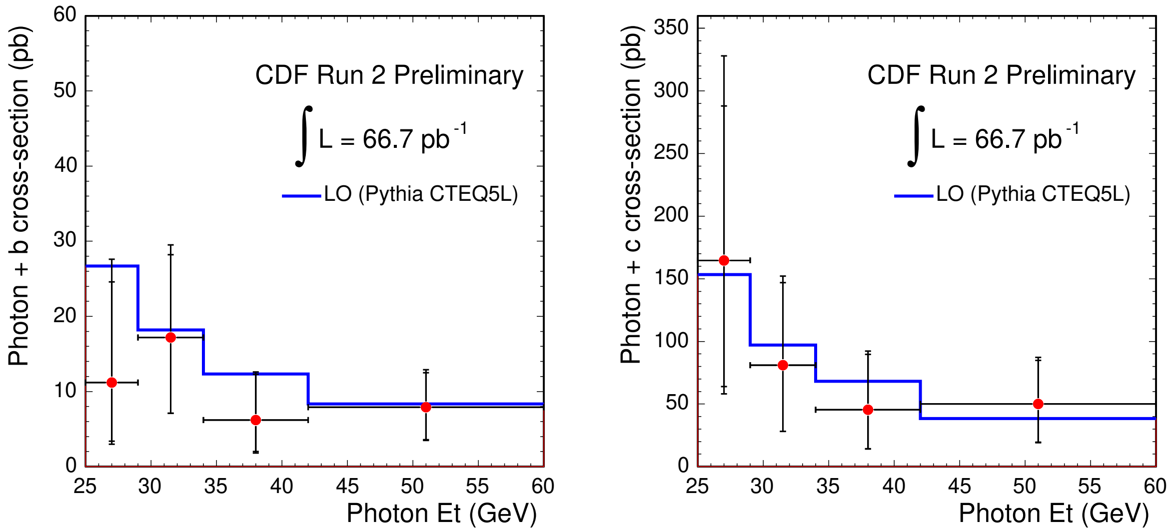

FIGURE 4. Differential cross section for b+γ and c+γ events

shown in figures 4, compared to LO MonteCarlo predictions (Pythia).

CONCLUSIONS

CDF has a broad program in heavy flavor production studies (not to mention decays, oscillations etc.), thanks mainly to its tracker. The main limitation is trigger and bandwidth; SVT allowed a large increase in low-pt b physics, giving CDF the largest world samples for exclusively reconstructed hadronic final states. This allowed measuring the b cross section in the J/Ψ channel. High-pt studies mainly used unbiased triggers. QCD analyses allowed measurements of b-and c- production for inclusive jets, multi-jets and jets in association with photons, allowing precision comparison with QCD calculations.

REFERENCES

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2. S.K. Choi *et al.*, Phys. Rev. Lett. **91**, 262001 (2003)