INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-91/022 (P)
6 Maggio 1991

B Physics at CDF

The CDF Collaboration

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Abstract

An overview of the B physics results obtained by CDF is presented. During the 1988-1989 run we have collected 4.4pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s}$ =1.8Tev. Using the $J/\psi \rightarrow \mu^+\mu^-$ sample the first reconstruction of exclusive B mesons decays at a hadron collider was obtained. From the inclusive electron sample and the exclusive B decays a measurement of the b quark production cross section was made and compared with the theory prediction. The $e\mu$ sample was used to study $B\bar{B}$ mixing and the χ parameter,averaged over B_d and B_s mesons, was measured to be χ =0.176±0.028(stat)±0.041(sys).

1 Introduction

B mesons have been extensively studied at e^+e^- colliders in the past ten years [1]. At the machines running at the $\Upsilon(4S)$ the masses of the B^0 and $B^\pm$ mesons, their branching ratios and decay kinematics were measured while the B lifetime was measured at the higher energy colliders.

At the Fermilab $p\bar{p}$ collider the b production cross section is large but the identification of the B decay products in presence of the high background characteristic of the hadronic interactions poses a challenging experimental problem. The measurement of the $p\bar{p} \rightarrow b + X$ production cross section is important as the uncertanties involved in its calculation are large. The high center of mass energy allows for the production and study of all kinds of B hadrons if the background can be reduced. At CDF we have achieved a favorable signal to background ratio in three data samples: the $J/\psi \rightarrow \mu^+\mu^-$ sample, the inclusive electron and the $e\mu$ sample.

2 The $J/\psi \rightarrow \mu^+\mu^-$ sample

The decay of B mesons into $J/\psi X$, where $J/\psi \rightarrow \mu^+\mu^-$, is particulary suited for the reconstruction of final states. Due to the large mass of the J/ψ the exclusive branching ratios of the two body decays are a big fraction of the inclusive $B \rightarrow J/\psi X$ rate. By mass constraining the muons of the $J/\psi \rightarrow \mu^+\mu^-$ decay, the B mass resolution is greatly improved. Furthermore the fraction of J/ψ from B decays is expected to be large in the high p_t and large angle region explored by CDF [2].

Muon identification at CDF [3] is obtained in the central region $|\eta| < 0.6$ by means of muons chambers surrounding the central calorimeter, each chamber consists of four drift planes. Stubs in the muon chambers are matched to tracks in the central tracking chamber (CTC) to define good muons. The dimuon trigger required a loose matching cut and a p_t cut on the muon tracks; the majority of the data was collected with a p_t cut of 3 GeV on both muons. The invariant mass distribution of the opposite signed dimuons corresponding to 4.0 pb^{-1} of integrated luminosity is shown in Fig. 1. The J/ψ sample is defined by requiring the dimuon invariant mass to be whithin ± 50 MeV of the J/ψ mass of 3097 MeV. This sample consists of 2500 J/ψ events above background.

Due to the trigger p_t cut on the muons the average p_t of the reconstructed J/ψ is $\approx$ 8 GeV . If these J/ψ come from B decays the momentum of the parent B meson must be even higher and its decay products are boosted forward and close to the J/ψ flight direction. The momentum of the K and π coming from the $B^\pm \rightarrow J/\psi K^\pm$ and $B^0 \rightarrow J/\psi K^{*0}$ decays is therefore expected to be larger than the average momentum of the particles associated with the underlying event.

To reconstruct a given decay final state the J/ψ legs are first constrained to the J/ψ mass. Combinations of the reconstructed J/ψ and the other tracks in a 60 degree cone around the J/ψ flight direction are formed with the relevant mass assignment. To search for $B^\pm \rightarrow J/\psi K^\pm$ combinations are formed with tracks with momentum above 3 GeV and the K mass assignment. The resulting invariant mass spectrum is shown in Fig. 2 where an excess of events is observed at the B mass. The search for $B^0 \rightarrow J/\psi K^{*0}$ is affected by a large combinatorial background. Due to the lack of particle identification at CDF for every pair of tracks, candidate $K^{*0} \rightarrow K^\pm\pi^\mp$, both K π and π K mass assignment must be given to the pair. To reduce this combinatorial background only the three highest momentum tracks in the 60 degree cone are used to form $K\ \pi$ pairs. If the $K\ \pi$ mass is whithin ± 50 MeV of the K^{*0} mass (896MeV) the $J/\psi K^{\pm}\pi^{\mp}$ combination is formed and the resulting invariant mass distribution is shown in Fig. 3 where a clear peak at the B mass is visible. Fig. 4 shows the sum of the $J/\psi K^{\pm}$ and the $J/\psi K^{*0}$ mass spectra. This demonstrates that the $J/\psi \rightarrow \mu^+\mu^-$ is a very good tag for B production at hadron colliders and can be employed to search for the yet undiscovered heavier B hadrons.

The $B^{\pm} \rightarrow J/\psi K^{\pm}$ reconstructed decays are used to measure the b quark production cross section. To relate the number of reconstructed B mesons in the $J/\psi K^{\pm}$ channel to the number of produced b quarks we use the following monte carlo method: b quarks are produced according to the p_t spectrum predicted by QCD [4], flat in rapidity for $|y^b| < 1$ and then fragmented in B hadrons according to the Peterson model [5]. We assume that a b quark fragments in a B^- meson 40% of the times. After the kinematics of the $B^{\pm} \rightarrow J/\psi K^{\pm}$ and $J/\psi \rightarrow \mu^+\mu^-$ decays is simulated and the analysis cuts applied we find that 90% of the reconstructed B mesons come from b quarks with $p_t^b >$10GeV. Therefore we choose to quote the b quark production cross section integrated for $p_t^b >$10GeV . Using the $B^{\pm} \rightarrow J/\psi K^{\pm}$ branching ratio measured at e^+e^- [6] and the calculated reconstruction efficiency our result for the cross section is:

$$\sigma(p\bar{p} \rightarrow b + X\ ,\ p_t^b > 10\text{GeV},\ |y^b| < 1) = (8.2 \pm 2.9(\text{stat}) \pm 3.3(\text{sys}))\mu b$$

3 The inclusive electron sample

Electron identification in CDF relys on the finely segmented central calorimeter, the proportional gas chamber embedded in the electromagnetic section of the calorimeter at shower maximum and the central tracking chamber. Good electrons are defined requiring that:

- only one track points to the calorimeter cluster,
- the ratio of the calorimeter energy to the track momentum be $0.75 < E/P < 1.4$,
- the ratio of the energy deposition in the hadronic and in the electromagnetic compartment be $HAD/EM < 0.04$,
- the energy sharing with adjacent towers must be in agreement with the expected electron lateral shower shape,
- in the proportional chamber the shower position must match the extrapolated CTC track and the shower shape must be compatible with a single electron as measured in the test beam.

Conversion electrons from interacting $\gamma \rightarrow e^+e^-$ and $\pi^0 \rightarrow \gamma e^+e^-$ are removed with 50% efficiency looking for a partner track with small opening angle with the candidate electron. The contribution of electrons from W decays is removed by the requirement that the missing E_t in the event be less than $8\sqrt{E_t}$ and electrons from Z decays are removed searching for a second electromagnetic cluster and requiring an invariant mass with the candidate electron less than 80 GeV. The p_t distribution of this prompt electron sample before and after the W and Z removal is shown in Fig. 5. This corresponds to 4.4pb^{-1} of data collected with an electron trigger threshold of p_t^e >12GeV and 200nb^{-1} (prescaled) with a trigger threshold of p_t^e >7GeV . We estimate a residual background of (20±5)% due to unidentified conversions and (15±15)% due to misidentified charged hadrons.

After background subtraction the source of prompt electrons is the heavy quarks semileptonic decay. At CDF b and c quarks are expected to be produced at similar rates but the harder fragmentation and the heavier b quark mass combined with the trigger p_t cut results in an enhancement of electrons from b decays in our sample. Using the Isajet monte carlo [7] we estimate a 10% charm fraction in our sample.

We have measured the b quark production cross section following the method employed by UA1 [8]. The monte carlo is used to relate the b production cross section to the observed electron rate. The b quark p_t^b spectrum is generated according to QCD [4], the Peterson model [5] is used for the fragmentation and the semileptonic B decay is generated with the kinematics measured at e^+e^- [9]. We choose to use three different region of the electron p_t^e spectrum and quote a b quark production cross section integrated for $p_t^b > p_t^{min}$ where p_t^{min} is chosen such that 90% of the electrons in the given region come from b quarks with p_t^b above p_t^{min} . The b cross section for the three kinematical regions is:

$p\bar{p} \to b + X$,$p_t^b > p_t^{min}$,$\|y^b\| < 1$		
p_t^e (GeV)	p_t^{min} (GeV)	$\sigma(nb)$
10-15	15	1220±390
15-20	23	220±70
20-25	32	56±18

Fig. 6 shows the experimental points obtained using the inclusive electrons together with the measurement from the B exclusive decays compared with the theory prediction [4]. The shape of the curve agrees well with the data while the absolute normalization of the theoretical calculation seems to underestimate the observed cross section.

4 The $e\mu$ sample

The phenomenon of mixing, or flavor oscillation, consists in the transformation of a neutral meson into its antiparticle through a second order weak transition. This phenomenon, well known in the $K^0\bar{K}^0$ system, has been studied recently in the $B^0\bar{B}^0$ system at $p\bar{p}$ and e^+e^- colliders [10] . The amount of mixing is sensitive to some of the yet unmeasured parameters of the standard model: the top mass and elements of the CKM matrix.

$B\bar{B}$ production followed by the semileptonic decay of the B hadrons is a source of dilepton events: ee,$\mu\mu$ and $e\mu$. First generation B decays produce unlike sign pairs while a second generation $b \to c \to lepton$ decay of one B hadron produces a pair with the same sign. The oscillation of one neutral B meson into its antiparticle also produces a like sign dilepton pair, therefore the signature of mixing is an excess of same sign dilepton events.

At a $p\bar{p}$ collider the ratio R of like sign to unlike sign lepton pairs is:

$$R = \frac{2\chi(1-\chi) + [(1-\chi)^2 + \chi^2]f_s}{[(1-\chi)^2 + \chi^2] + 2\chi(1-\chi)f_s + f_c}$$

where f_s is the fraction of second generation b decays and f_c the fraction of charm decays with respect the thė first generation b decays. The mixing parameter χ is the probability that a B^0 meson oscillates into a $\bar{B}^0$ meson averaged over B_d and B_s mesons: $\chi = P_d\chi_d + P_s\chi_s$ where P_d and P_s are the fraction of B_d and B_s mesons produced.

To measure R we use the $e\mu$ events, in this channel there is no contribution from Drell-Yan, J/ψ and Y production and the only background is due to fake electrons or muons. Electrons and muons candidates are required to have $E_t^e > 5$ GeV and $p_t^\mu > 3$ GeV. Electrons from conversions and from W decays are removed. Fig. 7 and Fig. 8 show the invariant mass of the like sign and unlike sign $e\mu$ pairs respectively. The peak at low mass for the unlike sign pairs is due to events from a single $b \rightarrow ce\nu_e$ followed by $c \rightarrow s\mu\nu_\mu$, we cut these events requiring M($e\mu$)>5 GeV. After these cuts we are left with 346 like sign events and 554 opposite sign events.

We estimate that the background due to fake electrons and muons is (20±10)% of the sample. After the mass cut the contribution to the background from the same sign and the opposite sign events is the same and the background subtracted value of R is :

$$R = 256/464 = 0.552 \pm 0.049(\text{stat})^{+0.039}_{-0.048}(\text{sys})$$

To extract the mixing parameter χ we estimate the fraction of secondary generation b decays to first generation b decays f_s and the fraction of charm decays to first generation b decays f_c using the monte carlo. At first order f_s and f_c depend on the relative c and b production cross section and the semileptonic branching ratios. Due to the analysis cuts f_s and f_c are also sensitive, to a lesser extent, to the c and b production mechanism. Taking into account the uncertaintes associated with these quantities and with the production mechanism we find that $f_s = (0.248 \pm 0.055)$ and $f_c = (0.066 \pm 0.066)$. The expected ratio of like sign to unlike sign lepton pair R_0 in absence of mixing is $R_0 = f_s/(1+f_c) = 0.233 \pm 0.051$ significantly lower than the observed ratio. From the measured R value we extract the χ parameter :

$$\chi = 0.176 \pm 0.028(\text{stat}) \pm 0.041(\text{sys})$$

in good agreement with the other measurements [10].

5 Conclusions

During the 1988-1989 run ≈ 10^7 high p_t b hadrons were produced at CDF. We have shown that samples of data useful for b studies can be obtained at $p\bar{p}$ collisions.

Thanks to the excellent momentum resolution the decays $B^\pm \rightarrow J/\psi K^\pm$ and $B^0 \rightarrow J/\psi K^{*0}$ were fully reconstructed in the $J/\psi \rightarrow \mu^+\mu^-$ sample. Good lepton identification is essential to obtain b rich samples in the inclusive electron and $e\mu$ data. From the inclusive electron sample the b quark production cross section was measured and $B\bar{B}$ mixing was studied with the $e\mu$ data. In the next run, with higher luminosity, extended muon coverage and a silicon vertex detector the sample of reconstructed decays should be much larger and our B physics capabilities increased.

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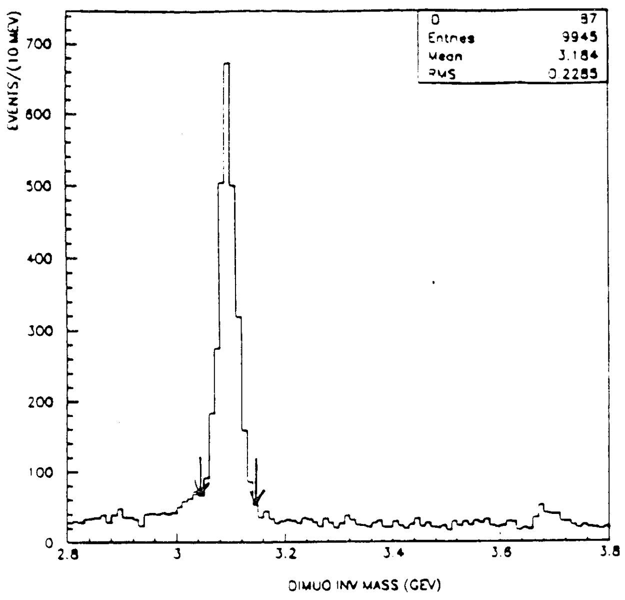


Fig.1

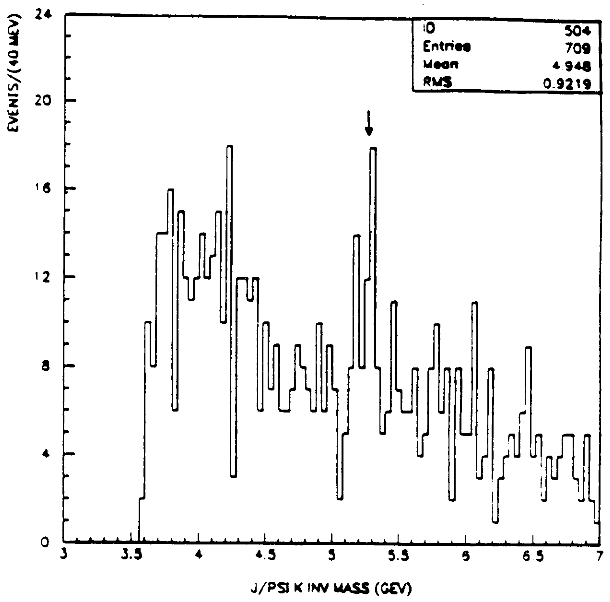
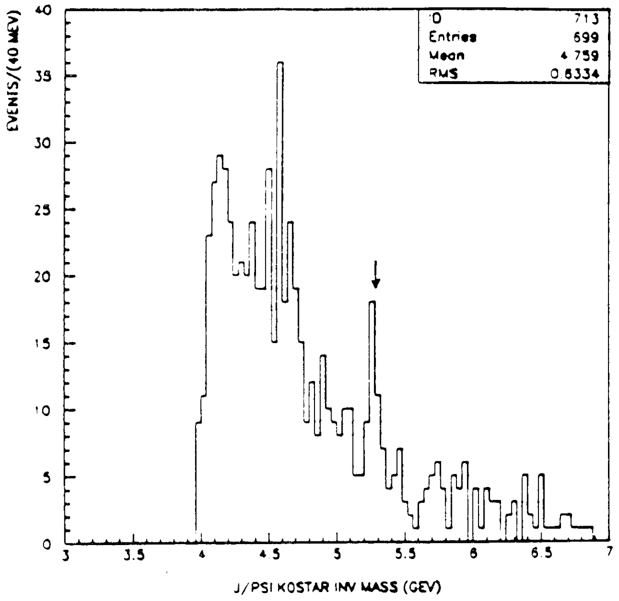


Fig.2



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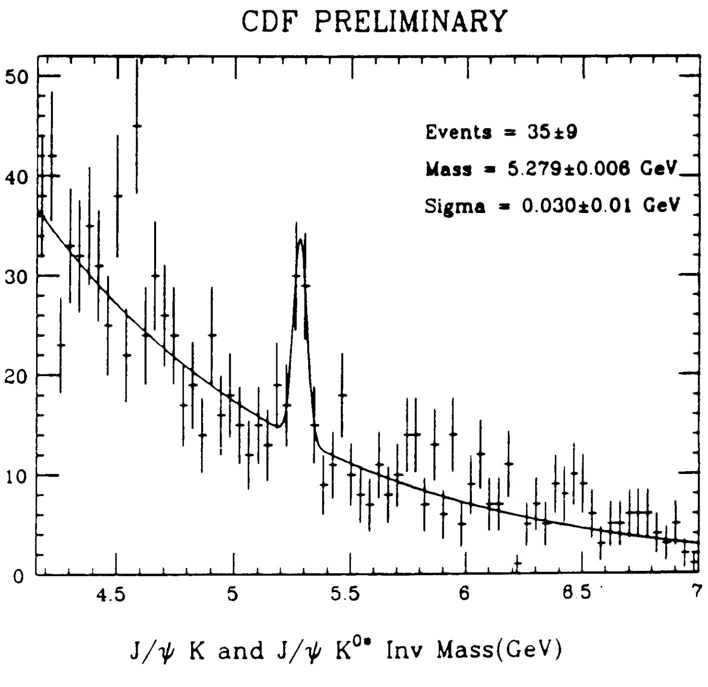

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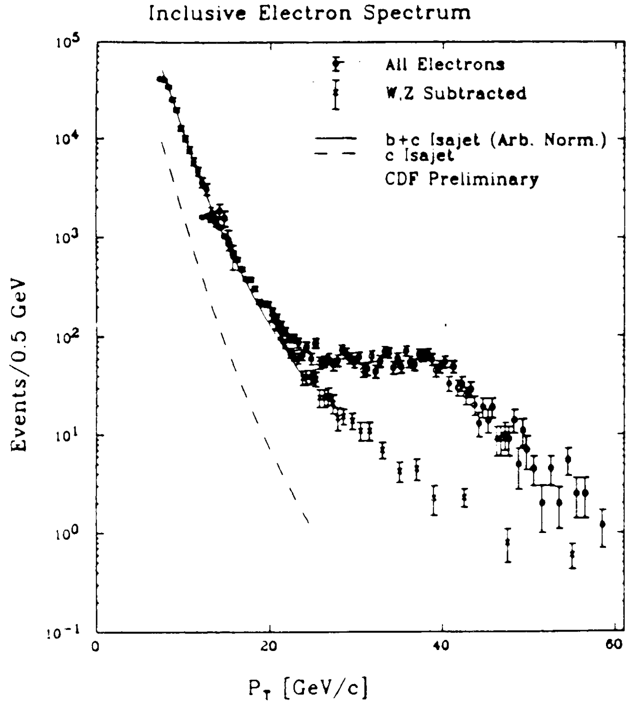

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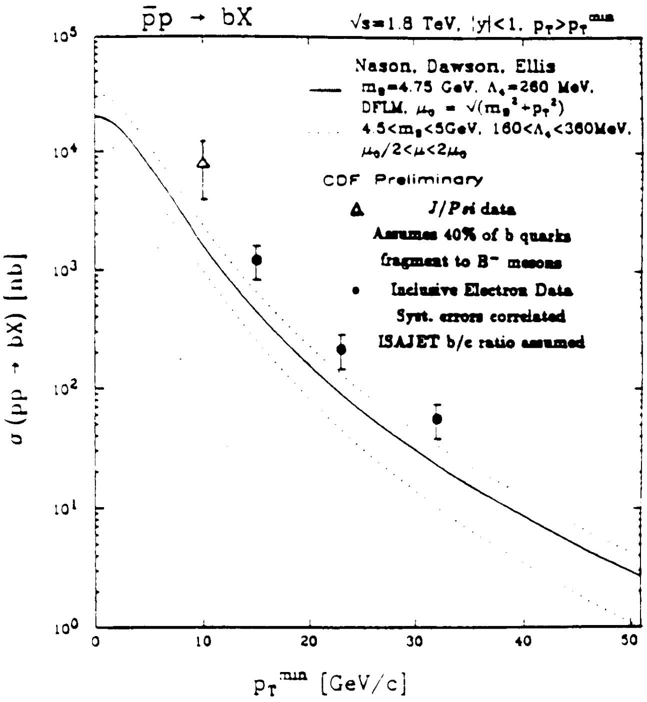

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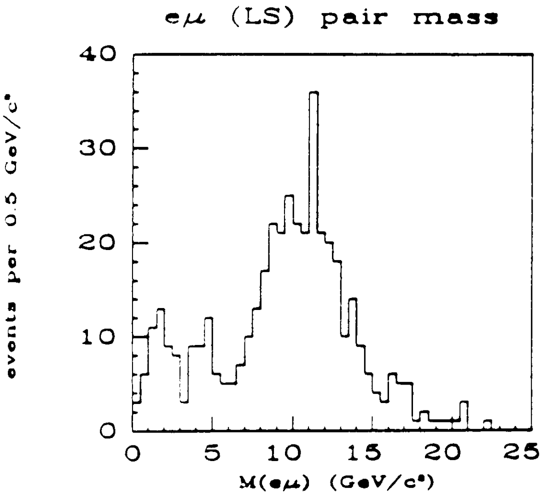

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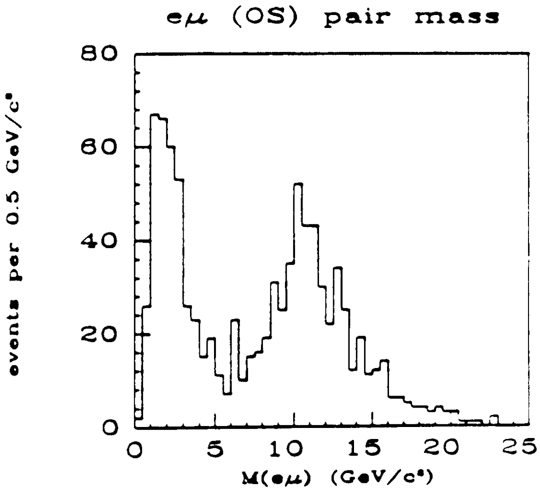

Fig.8