B-Physics at Fermilab DØ Experiment - Present and Prospects*

G. A. Alves

LAFEX/CBPF

Rua Dr. Xavier Sigaud 150, Rio de Janeiro, RJ

(Representing the D0 Collaboration†)

Abstract

We present the first B-Physics results from the 1992/93 collider run at Fermilab, using the DØ detector. Results are given for the b-quark production cross section using inclusive single muons and J/ψ to tag the heavy flavor production. Preliminary results on $B^\circ - \bar{B}^\circ$ Mixing are also presented. We compare the results with theoretical predictions where appropriated and present the prospects for future runs.

*Talk presented at XVI Encontro Nacional de Física de Partículas e Campos, Caxambu, Brazil, October 24-28, 1995

†Universidad de los Andes (Colombia), University of Arizona, Brookhaven National Laboratory, Brown University, University of California,Davis,Irvine,Riverside, Centro Brasileiro de Pesquisas Físicas (Brasil), CINVESTAV (Mexico), Columbia University, Delhi University (India), Fermilab, Florida State University, University of Hawaii, University of Illinois, Chicago, Indiana University, Iowa State University, Korea University (Korea), Lawrence Berkeley Laboratory, University of Maryland, University of Michigan, Michigan State University, Moscow State University (Russia), New York University, Northeastern University, Northern Illinois University, Northwestern University, University of Notre Dame, Panjab University (India), Institute for High Energy Physics (Russia), Purdue University, Rice University, University of Rochester, CEN Saclay (France), State University of New York,Stony Brook, SSC Laboratory, Tata Institute of Fundamental research (India), University of Texas, Arlington, Texas A&M University

1 Introduction

Although the DØ experiment is optimized for high p_T physics, its extensive muon detection system capable on triggering on muons in a large pseudorapidity range, combined with the large $b\bar{b}$ cross section at $\sqrt{s} = 1.8$ TeV make it possible to study the b production in single muon and multimuon channels. The inclusive single muon and J/ψ cross sections, measured as a function of muon transverse momentum p_T^μ and pseudorapidity η, can be used to infer the $b\bar{b}$ cross section for which QCD predictions have been calculated in the in next-to-leading (NLO) order [1]. Measurement of heavy quark production at large pseudorapidity provides information on the gluon structure function at small x.

2 DØ Detector

The DØ detector [2] is a large general purpose facility with no central magnetic field. The detector consists of central drift chambers, a transition radiation detector, a highly segmented liquid-argon uranium calorimeter with good energy resolution and a muon system.

The muon detector consists of five magnetized iron toroids between the first two of the three layers of proportional drift tubes. It provides a measurement of a muon momentum over a pseudorapidity range $|\eta| < 3.3$. The momentum resolution is limited by the Multiple Coulomb scattering to $\geq 20\%$. Test beam data indicate that the intrinsic diffusion limit on the spacial resolution is ≈ 200 μm. The resolution is currently limited to 700 μm by the accuracy of the geometric alignment. The central tracking system helps in identifying muons associated with the interaction vertex. The calorimeter coverage extends down to $|\eta|$ of ≈ 4.4 and is used in this analysis to detect jets associated with the muons. The total thickness for the calorimeter plus the toroid varies from 13 to 18 λ and reduce the hadron punchthrough to a negligible level. The DØ detector design was optimized keeping in mind three main objectives:

- Provide excellent identification and energy measurement for electrons and muons, as one expects that new phenomena generally have large branching fractions into final states with one or more leptons. On the other hand, those processes typical of QCD, which are much more frequent, have comparatively lower semileptonic branching fractions.
- Allow the observation of parton jets with excellent energy resolution. Emphasis was given to the observation of parton jets instead of the individual particles, because the jets as a whole are more directly related to the fundamental processes occurring in a high energy collision than each isolated particle.
- Provide a good measurement of $\not\!\!E_T$, the missing energy necessary to transverse energy-momentum balance, as an indirect means of detecting neutrinos and other neutral particles with low interaction rate with matter.

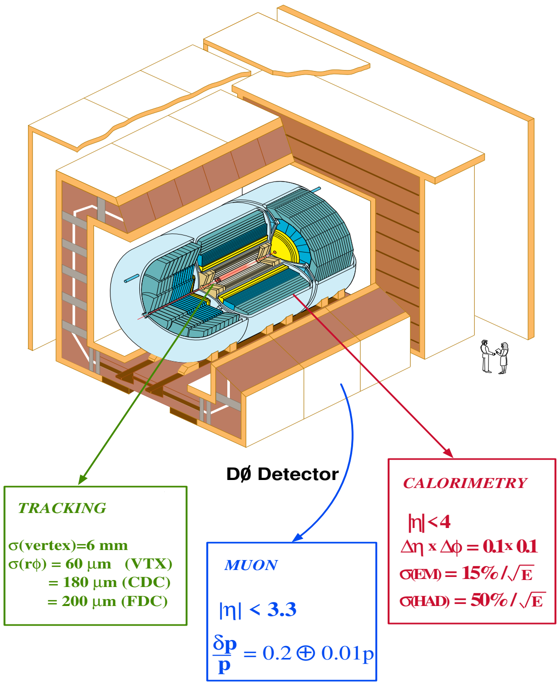


Figure 1: Isometric view of the DØ Detector showing its subcomponents

3 Inclusive muon Cross Section

3.1 Event Selection

The DØ event selection consists of 3 levels of trigger [2] which reduces $\approx 43\ mb$ [3] of inelastic cross section to 2 Hz of data written to magnetic tape. The Level 0 trigger selects inelastic collisions from beam-beam scintillator coincidences and measures the vertex position. Level 1 hardware muon trigger requires 2 hits in either 2 or 3 layers of the muon system, depending on the geometric region, in a coarse road of 60 cm width. The efficiency of the Level 1 muon trigger for high p_T muons is $\approx 60\%$, the losses being mostly geometric. The Level 2 software muon trigger requires a good quality muon track with the reconstructed transverse momentum $p_T^\mu > 3$ GeV.

3.2 Data Analysis

The inclusive muon cross section measurements are based on special runs taken at low luminosity. These runs used single muon triggers for two regions of pseudorapidity, central ($\mid \eta \mid < 1$) and forward ($2.2 < \mid \eta \mid < 3.3$), with integrated luminosities of $73.3 nb^{-1}$, and $37.7 nb^{-1}$, respectively. The data presented here comes from the 1992/93 collider run. The results for the forward region are still preliminary.
For the offline analysis the muon was required to have $p_T^\mu > 5$ GeV. Quality cuts require: hits in all the three layers of the muon system; a matching central detector track; at least 1 GeV

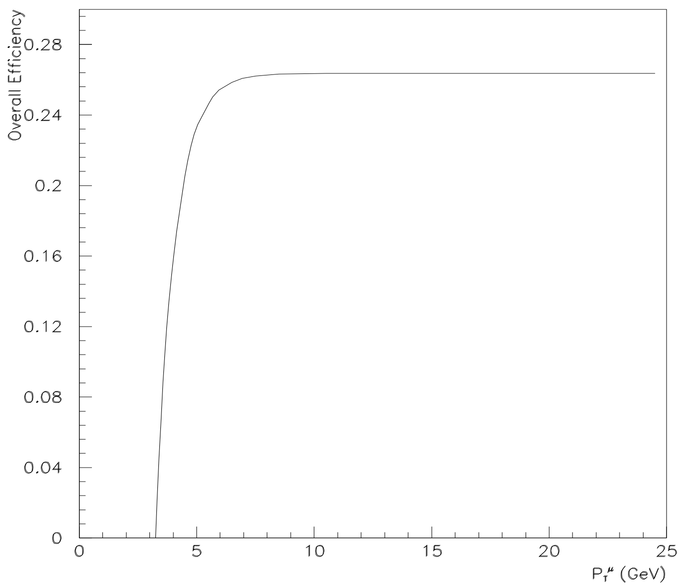


Figure 2: Overall efficiency for muons with $|\eta| < 1$.

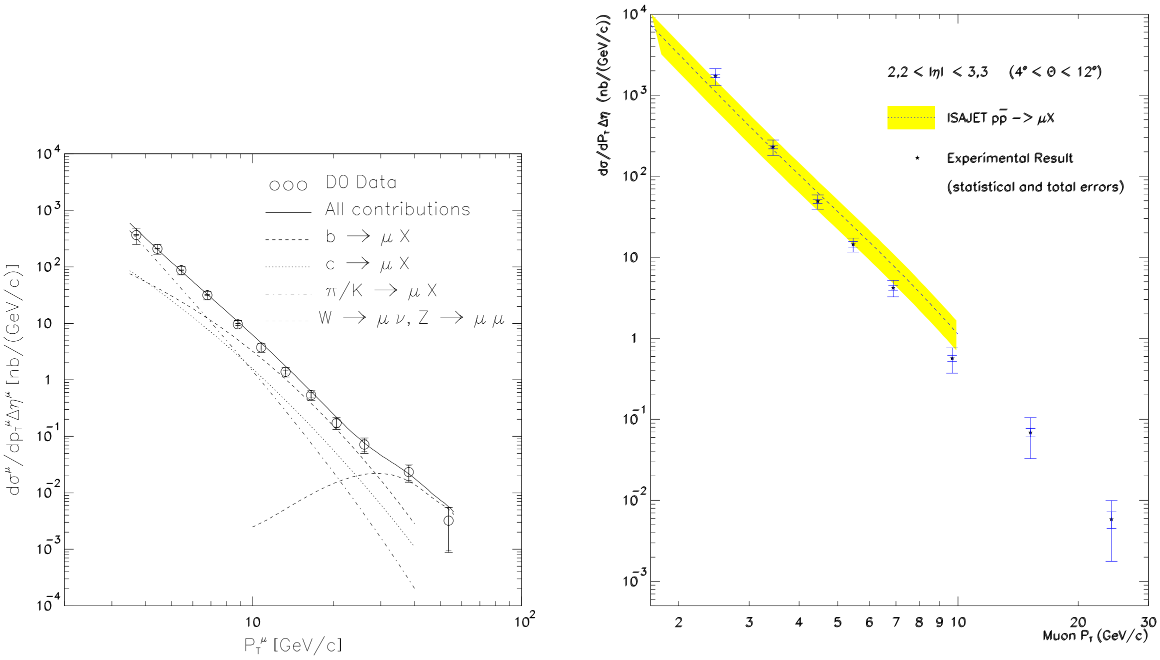
energy deposition in the calorimeter; good impact parameter vertex projection in both bend and non-bend views; the muon track passing cosmic ray rejection cuts and synchronized within $100ns$ with the beam crossing time.

For the single muon analysis the overall efficiency was evaluated using ISAJET [4] $b\bar{b}\rightarrow \mu X$ Monte Carlo events. These events were put through a complete GEANT detector simulation, Level 1 and Level 2 trigger simulators and the offline event reconstruction. As shown in Figure 2, the overall efficiency is 26% for $p_T^\mu > 5$ GeV and $\mid \eta \mid < 1$. Muons with $2.2 < \mid \eta \mid < 3.3$, have an overall efficiency of $\approx 17\%$.

3.3 Results and Discussion

The inclusive muon cross section for the two pseudorapidity regions, $\mid \eta \mid < 1$ and $2.2 < \mid \eta \mid < 3.3$, is shown in Figures 3(a) and 3(b), respectively. The main sources of systematic error are the uncertainty in the luminosity measurement (12%) and the cosmic ray and combinatoric backgrounds ($\approx 10\%$ for $|\eta| < 1$). The data have been compared to (NLO) ISAJET Monte Carlo predictions. Figures 3(a) and 3(b) show the predicted contributions to the cross section from b$\rightarrow \mu X$, c$\rightarrow \mu X$, and π or K decays summed together.

The shape of the p_T^μ spectrum is in good agreement with expectation. Although no jet was required either in the trigger or the analysis, it was found that nearly 60% of the events have jets associated with them, suggesting that most of the events are indeed from b decays as expected.



(a) $\mid \eta \mid < 1$ (b) $2.2 < \mid \eta \mid < 3.3$

Figure 3: Inclusive muon cross sections compared to Monte Carlo predictions from ISAJET

Work is in progress to decrease the systematic uncertainties and to extract the $b\bar{b}$ cross section in the forward region. In the central region, the $b\bar{b}$ cross section was extracted following a general procedure developed by the UA1 collaboration [5].The relation between the b-quark cross section and the experimental muon spectrum is given by:

$$\sigma^b(p_T^b > p_T^{min}) = \tfrac{1}{2}\ \sigma_b^{\mu}(p_T^{\mu 1}, p_T^{\mu 2})\ \frac{\sigma_{MC}^b}{\sigma_{MC}^{\mu}} \quad , \tag{1}$$

where $\sigma_b^{\mu}(p_T^{\mu 1}, p_T^{\mu 2})$ is the muon cross section integrated over the interval $p_T^{\mu 1} < p_T^{\mu} < p_T^{\mu 2}$. The resulting cross section as a function of p_T^{min} is shown in Figure 4, where similar CDF [6] measurements using inclusive leptons are shown for comparison. Details of this work can be found in ref. [7] and in the Ph.D. thesis of V. Oguri and J.G.R. Lima [8]

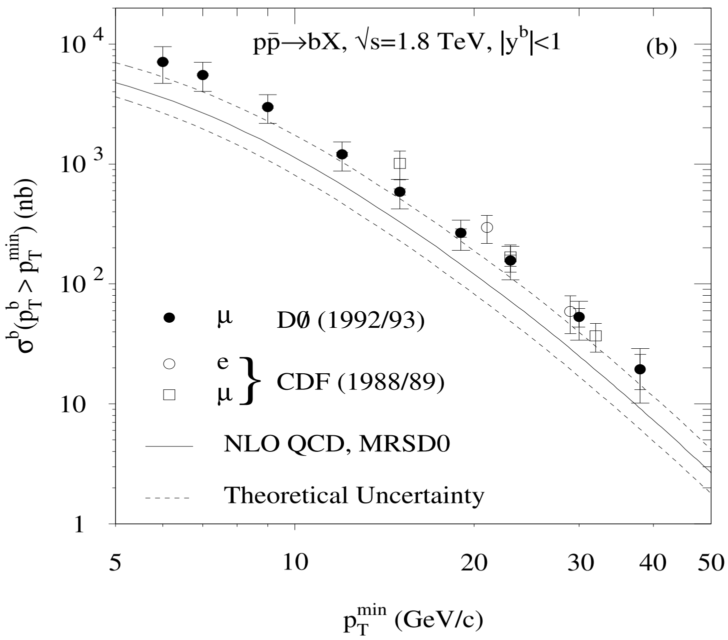


Figure 4: b-quark production cross section compared to NLO QCD predictions of NDE using MRSD0 structure functions, Ref. [1].

4 Inclusive J/ψ Cross Section

4.1 Event Selection

For the J/ψ study it was required that the events have at least two muons at both Level 1 and Level 2 trigger, with $p_T^\mu > 3$ GeV at Level 2. The data for this analysis were taken during normal high luminosity runs, and correspond to a total integrated luminosity of $6.6pb^{-1}$. It represents a totally independent sample from the one used for the single muon analysis.

4.2 Data Analysis

In the offline analysis two good quality muons were required in the fiducial volume $\mid \eta \mid < 1.0$ with a dimuon transverse momentum $p_T^{\mu\mu}$> 8 GeV. In addition, both muons were required to be consistent with the reconstructed vertex position, to have a calorimeter energy deposition consistent with a minimum ionizing particle and not be back to back in η and ϕ ($\Delta\theta$< 170° and $\Delta\phi$< 160°) to avoid cosmic background contamination. In view of our modest dimuon mass resolution, $\approx 12\%$ at the J/ψ mass, we limit the invariant mass of this analysis to $M_{\mu\mu} < 6GeV/c^2$

4.3 Results and Discussion

Muons coming from leptonic decays of b quarks are associated with jets, while Drell-Yan processes and direct charmonium production yield muons isolated from jets. Other mechanism that generate isolated dimuons is the decay of light quark mesons, such as ρ, ϕ, and η.

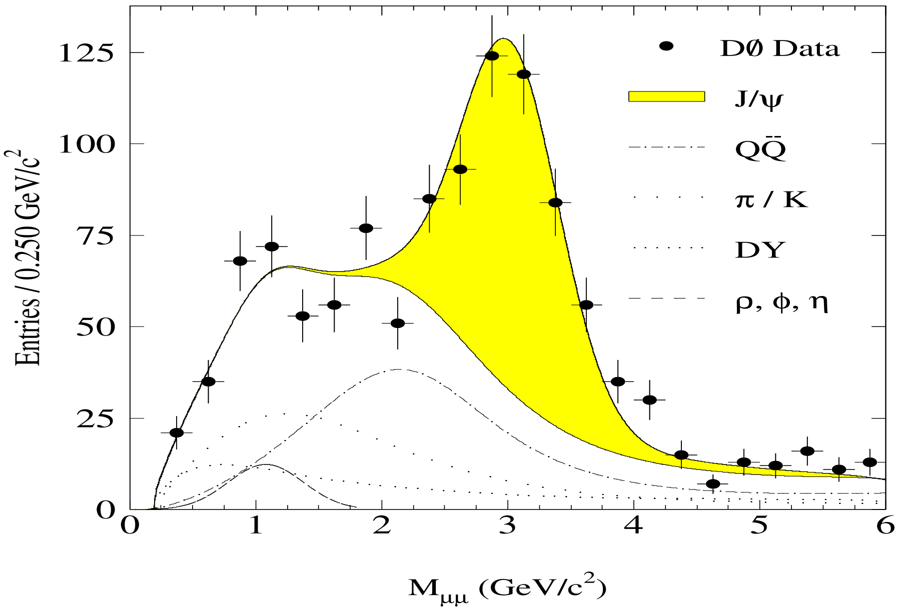


Figure 5: The mass spectum for opposite sign muon pairs. The solid curve is the fitted sum of the J/ψ signal and background contributions.

Isolated dimuons are defined such that neither muon is associated with a jet with $E_T > 8$ GeV, within 0.7 in η,ϕ space. If one or both of the muons are within a jet, the muon pair is defined to be non-isolated. For non-isolated dimuons we define $p_T^{\mu\mu}{}_{rel}$ as the transverse momentum of the dimuon with respect to the associated jet.
For each of the dimuon production processes mentioned above, we generated a sample of Monte Carlo events using the ISAJET program. To estimate the relative contribution of each process we applied a maximum likelihood fit to the invariant mass($M_{\mu\mu}$), Isolation and $p_T^{\mu\mu}{}_{rel}$ distributions. The results are shown in Fig. 5. The total estimated number of J/ψ events is 407±28, of which 147±33 are isolated.

The inclusive J/ψ production cross section as a function of transverse momentum is shown in Fig. 6. The data points are shown with statistical and p_T dependent systematic errors added in quadrature. Also plotted are theoretical predictions [9]. They agree with our measurement within the total experimental and theoretical uncertainty but tend to be less steeply falling with p_T.

To determine the fraction f_b of J/ψ from B meson decays, we have examined the distribution of the impact parameter of the muons relative to the event vertex, in the $r - \phi$ plane. We have performed a simultaneous mass and impact parameter maximum likelihood fit to the opposite sign dimuon data. The resulting value of the J/ψ b fraction from this fit is $f_b = 0.35 \pm 0.09(stat) \pm 0.10(syst)$. Using this fraction, we determine the b quark cross section using the same method explained for the single muon data. The resulting integrated cross section as a function of p_T^{min} is shown in Fig. 7 together with the inclusive muon results.

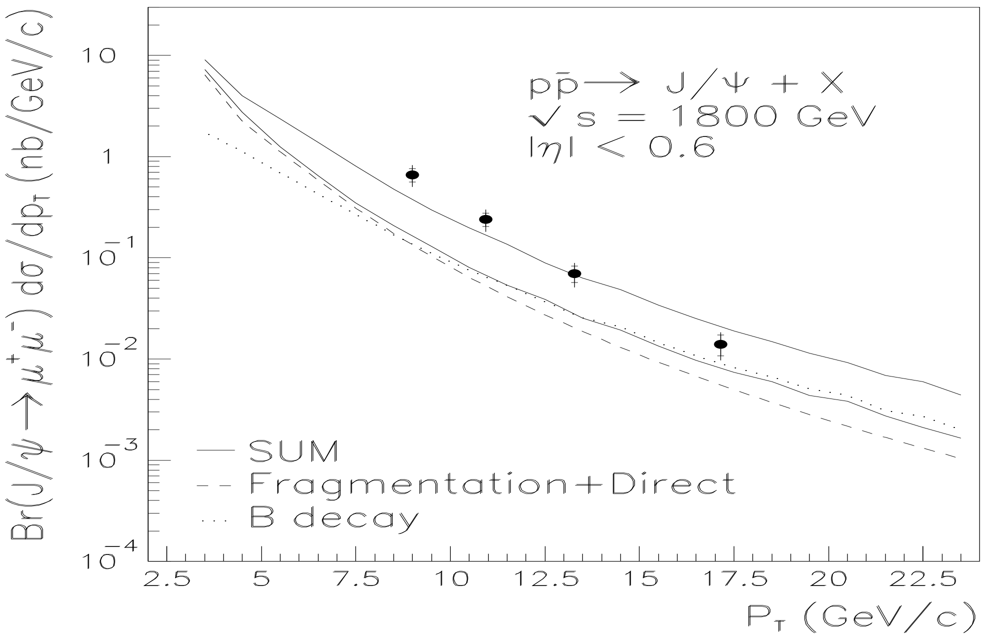


Figure 6: Inclusive J/ψ cross section times Branching Ratio into muons.

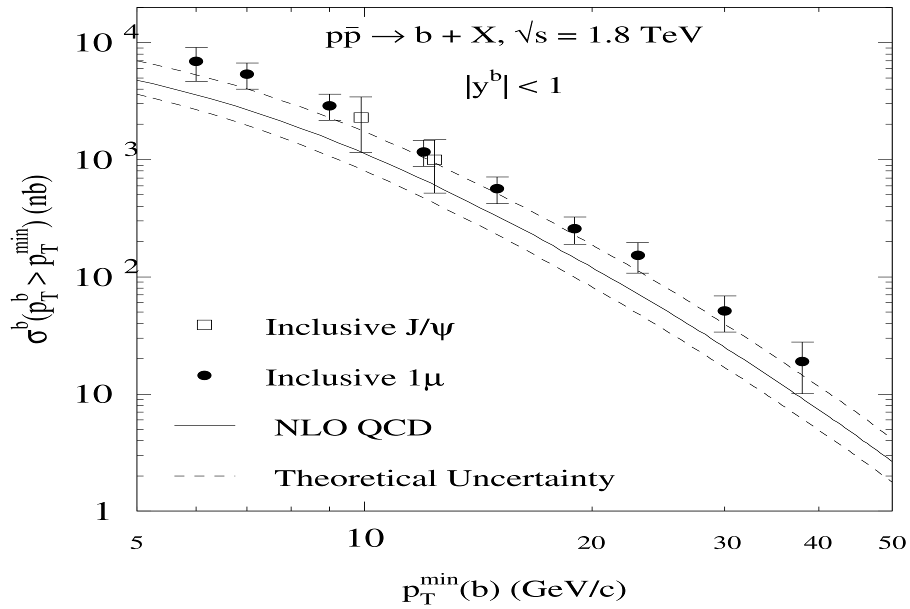


Figure 7: Integrated b quark production cross section vs p_T^{min}. The curve represents the QCD NLO prediction of NDE, Ref. [1].

5 $B^\circ - \bar{B}^\circ$ Mixing

$B^\circ - \bar{B}^\circ$ mixing can occur in the Standard Model through the well-known box diagrams, which result from the non-conservation of quark flavor in the weak interaction.
In the case of semileptonic decay of B mesons into muons, the time averaged mixing probability χ can be writen as

$$\chi = \frac{P(B^0 \to \overline{B^0} \to \mu^- X)}{P(B^0 \to \mu^+ X) + P(B^0 \to \overline{B^0} \to \mu^- X)} \tag{2}$$

which is an average over both B_d^0 and B_s^0 mesons.
Experimentally, one measures the ratio R of like to unlike sign dimuons. In order to extract χ from R it is necessary to model the relative contributions of all processes which contribute to dimuon production.

5.1 Event Selection

The data set used in this preliminary analysis was collected using both a dimuon and a single muon plus jet trigger. The dimuon trigger was the same used for the J/ψ analysis, while the muon plus jet trigger required one muon candidate in $|\eta| < 1.7$ with $p_T^\mu > 3$ GeV/c, and one reconstructed jet in $|\eta| < 3.5$ with $E_T^{jet} \geq 10$ GeV. The corresponding integrated luminosity for these triggers was 10.3 pb^{-1} .

5.2 Data Analysis

The offline requirements for this analysis were essentially the same as for the J/ψ case, except for the dimuon invariant mass, required to be between 6 GeV and 40 GeV, in order to remove events from J/ψ and Z^0 decay. Correcting for the estimated cosmic ray background, we find the ratio of like to unlike sign dimuons to be

$$R = \frac{likesign}{unlikesign} = 0.43 \pm 0.07(stat) \pm 0.05(syst) \tag{3}$$

The relative contributions of the different dimuon production processes were determined using ISAJET Monte Carlo plus the full DØ detector and trigger simulations. Sources of systematic error to the relative fractions given by Monte Carlo were investigated using checks from the data wherever possible.

5.3 Results and Discussion

Combining the experimental parameter R, as given above, with the relative fractions of the dimuon production processes, we determine the time and flavor averaged mixing probability to be

$$\chi = 0.09 \pm 0.04(stat) \pm 0.03(syst) \tag{4}$$

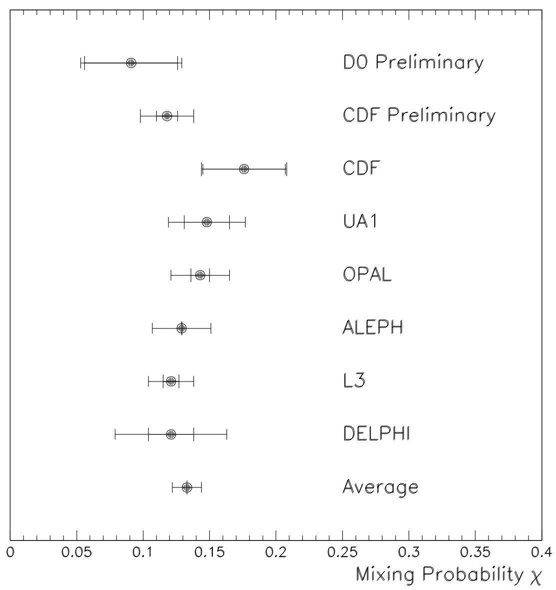


Figure 8: Mixing probability measurements. The average does not include the preliminary DØ and CDF results.

The measured value for χ is in agreement with other recent experimental results from UA1, CDF and LEP [10] as shown in Fig. 8.

6 Summary

The DØ experiment has completed several analysis with data from its first run, using nearly 15 $pb^{-1}$of data. We have measured the inclusive muon and the inclusive J/ψ cross-sections, and extracted from them the b quark cross section. The cross section results in both cases are in general agreement with the values expected from QCD calculations in the next to leading order. Preliminary results for $B^\circ - \bar{B}^\circ$ mixing were also obtained using muons to tag the heavy flavor decay. The measured value for the averaged mixing probability is in agreement with recent results from other experiments. Searches for Υ, χ states, as well as for additional particles such as K_S° and Λ associated with the J/ψ are in progress. We expect to increase our statistics by a factor of 5-10 using new data coming from the second run (Run 1b) scheduled to end by february 1996.
Several upgrades of the DØ detector are scheduled for the Main Injector era, near 1998, including a new Silicon Vertex Detector and a central magnetic field, which will improve both the momentum resolution and the capability to detect the secondary vertex from beauty decays. These improvements will enhance our B-Physics program for the future, with the addition of exclusive decay channels, search for rare B decays, CP violation and much more.

7 Acknowledgements

We would like to thank the technical staff of Fermilab and other collaborating institutions for their support. Funding has been provided by the U.S. Department of Energy, the U.S. National Science Foundation, the CNPQ in Brazil, the Colciencias in Columbia, the Commissariat a l' Energie in France, the State Committee for Atomic Energy in Russia and the Department of Energy in India.

References

[1] P. Nason, S. Dawson and R. K. Ellis, *Nucl. Phys.* **B303** (1988) 607; **B327** (1989) 49. W. Beenaker, H. Kuijf, W. L. van Neervan and J. Smith, *Phys. Rev.* **D40** (1989) 54. W. Beenaker, W. L. van Neervan, R. Meng, G. Schuler and J. Smith, *Nucl. Phys.* **B351** (1991) 507.

[2] S. Abachi *et al.*, "The DØ Detector", NIM **A338** (1994) 185

[3] K. Hikasa *et al.*, Review of Particle Properties, Particle Data Group *Phys. Rev.* **D45** (1992) III.84.

[4] F. Paige and S. Protopopescu, BNL Report no. BNL38034, 1986 (unpublished), release v 7.0.

[5] UA1 Collaboration, C. Albajar *et. al.*, Phys. Lett. **B213**, 405 (1988); **B256**, 121 (1991).

[6] CDF Collaboration, F. Abe *et. al.* , Phys. Rev. Lett. **68**, 3403 (1992); **69**, 3704 (1992); **71**, 500, 2396, 2537 (1993); Phys. Rev. D **50**, 4252 (1994).

[7] S. Abachi *et al.*, Phys. Rev. Lett., **74** (1995) 3548

[8] V. Oguri, Ph.D. Thesis, Centro Brasileiro de Pesquisas Físicas, August 1995(unpublished)

J.G.R. Lima, Ph.D. Thesis, Centro Brasileiro de Pesquisas Físicas, May 1995(unpublished)

[9] M. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. **B373** (1992) 295

[10] C. Albajar *et al.*, Phys. Lett **B262** (1991) 171

F. Bedeschi (CDF collaboration), *Proc. of the 10th Topical Workshop on Proton-Antiproton Collider Physics*, Fermilab (1995)

P. Abreu *et al.*, Phys. Lett. **B301** (1993) 145