Measurement of Polarization of Heavy Mesons at the Collider Detector at Fermilab

Heather Kay Gerberich, for the CDF Collaboration

University of Illinois, Urbana, Illinois 61801, USA

Abstract. We present a preliminary measurement sensitive to the Υ(1S) polarization in dimuon events from $p\bar{p}$ collisions at 1.96 TeV, using the CDF II detector at the Fermilab Tevatron. The measurement is conducted over a p_T range of 2-40 GeV/c, based on data comprising an integrated luminosity of 2.9 fb^{-1}.

Keywords: Upsilon Polarization, Bottomonium, Charmonium
PACS: 14.40.Pq, 13.20.Gd

INTRODUCTION

Quarkonium production and polarization is not adequately described by the Quantum Chromodynamics Color Singlet Model (CSM). In the CSM, one naively expects prompt vector-meson production to be suppressed because three high q^2 gluons are needed to produce the colorless state [1]. However, CDF Run I measurements found prompt J/ψ and ψ' production to be significantly enhanced, with the ψ' cross section fifty times the leading order expectation [2]. Non-Relativistic Quantum Chromodynamics (NRQCD) theory introduces a color octet model that accurately predicts the J/ψ and Υ production cross section [3]. However, NRQCD does not correctly model charmonium polarization, predicting strong transverse polarization at high momentum ($p_T/M \gg 1$) [4] while the CDF Run I and Run II data show a trend toward longitudinal polarization at high p_T [5]. There is some question as to whether charm quarks are heavy enough to be modeled as non-relativistic particles. Thus the measurements of the properties of bottomonium are essential. This proceeding describes an Υ(1S) polarization measurement using 2.9 fb^{-1} of CDF data.

DECAY ANGLE DISTRIBUTIONS IN THE HELICITY FRAME

The parameter α describes the shape of the angular distribution $\frac{dN}{d(\cos\theta^*)} \propto 1+\alpha\cos^2\theta^*$ where θ^* is defined as the angle between the μ^+ direction in the Υ rest frame and the Υ momentum direction in the laboratory frame. The polarization is fully transverse when $\alpha = 1$ and fully longitudinal when $\alpha = -1$. This s-channel helicity frame has historically been preferred for polarization measurements at high p_T collider experiments.

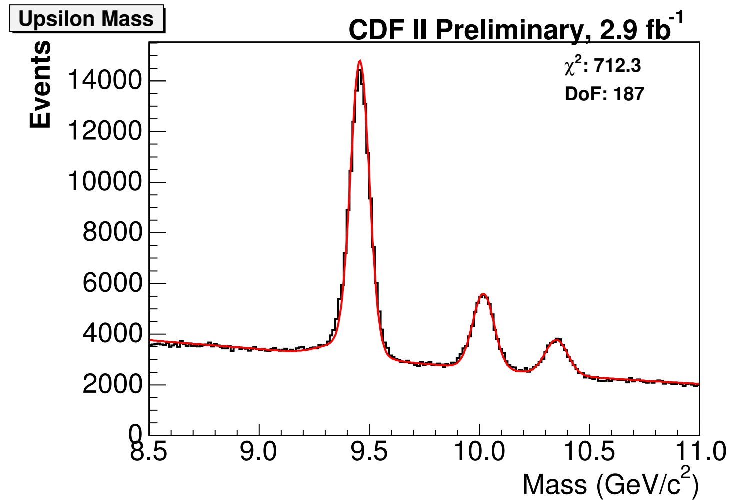

FIGURE 1. Υ mass distribution using 2.4 fb^{-1} yields $\sim$83,000 events for Υ(1S).

Υ CANDIDATE SELECTION

Υ candidates are selected online using central ($|\eta| < 0.6$) dimuon triggers which require loose matching between charged particle tracks in the central drift chamber to muon hit segments in the central muon drift chambers followed by the requirement that the dimuon mass lies in the Υ mass region between 8.0 and 12 GeV/c^2. Additional track quality, acceptance, dimuon vertex probability, and L_{xy} cuts are imposed in the offline analysis. The resulting dimuon invariant mass spectrum is shown in Figure 1, yielding approximately 83,000 Υ(1S) signal events in 2.9 fb^{-1} of data.

POLARIZATION MEASUREMENT

To measure the Υ polarization, the $\Upsilon \to \mu^+\mu^-$ yield is determined in bins of p_T and $\cos\theta^*$. The Υ yield measurements are performed in eight bins of p_T of varying widths between 2 GeV/c and 40 GeV/c. Then, in each p_T bin, the $\Upsilon \to \mu^+\mu^-$ yield is measured in 10 bins of $\cos\theta^*$. A template method is used to correct for apparatus acceptance and trigger conditions that affect the angular distribution of the signal. The templates are generated using simulated samples of Υ generated with fully transverse ($\alpha = 1$) and fully longitudinal polarizations ($\alpha = -1$). These templates are weighted to find the proper admixture of polarization that agrees with the data.

Proper treatment of the background is crucial to the measurement of the Υ polarization. To correct for the background in the Υ data sample, the angular distribution ($\cos\theta^*$) of the background in the Υ mass side-band regions is measured. Simultaneous fits are then made to the polarization parameter and background in bins of $\cos\theta^*$. The results of these fits for three p_T ranges are shown in Figure 2. The figures show that the higher p_T bins are most sensitive to differences between polarization hypothesis but suffer from acceptance limits.

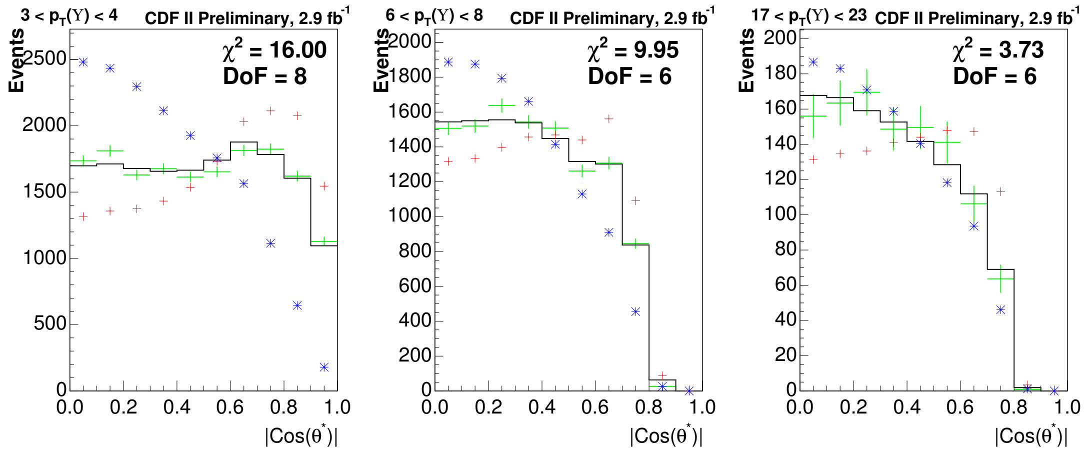

FIGURE 2. Υ yield as a function of $\cos\theta^*$ in a low, medium, and high p_T region. The green points are the data, the blue points represent the longitudinal template, the red points show the transverse template, and the black distribution shows the best fit combination.

SYSTEMATIC UNCERTAINTIES

Several potential sources of systematic uncertainties were studied including the muon efficiency function used in the simulation, the Υ mass parametrization and signal range, the minimum muon p_T requirement, the fitting technique, and the $\cos\theta^*$ bin width and resolution. The largest source of systematic uncertainty was due to the muon efficiency function and was found to be small; the remaining sources were negligible. The overall precision on this measurement is limited by statistical uncertainty.

RESULTS

Having measured the yields in bins of p_T and $\cos\theta^*$ and performed fits to determine the proper admixture of the longitudinal and transverse templates, we extract the polarization parameter α as a function of p_T as shown in Figure 3. We observe almost zero polarization at low p_T with a trend toward longitudinal polarization with increasing p_T. The green band shows the NRQCD prediction which indicates transverse polarization at high p_T [4].

SUMMARY AND PLANS

The polarization as a function of p_T of the $\Upsilon(1S)$ has been measured at CDF using 2.9 fb^{-1}. The result does not agree well with NRQCD predictions. Thus, the puzzle of heavy quark vector-meson properties remains. The CDF measurement can be improved with the inclusion of additional data, the analysis of angular distributions in alternative reference frames (e.g., Collins-Soper), and refined measurement techniques.

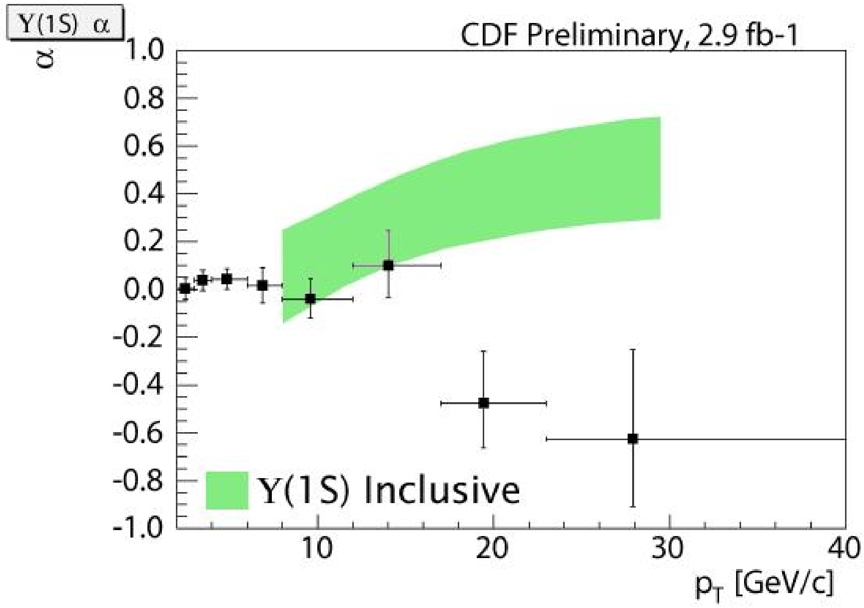

FIGURE 3. Υ(1S) prompt polarization, including feed-down from χ_b and Υ(nS) states. The green band is the NRQCD prediction including feed-down [4].

ACKNOWLEDGMENTS

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean World Class University Program, the National Research Foundation of Korea; the Science and Technology Facilities Council and the Royal Society, UK; the Institut National de Physique Nucleaire et Physique des Particules/CNRS; the Russian Foundation for Basic Research; the Ministerio de Ciencia e Innovación, and Programa Consolider-Ingenio 2010, Spain; the Slovak R&D Agency; the Academy of Finland; and the Australian Research Council (ARC).

REFERENCES

1. R. Baier and R. Ruckl, Z. Phys. C **19**, 251 (1983).
2. F. Abe *et al.* [CDF Collaboration], Phys. Rev. Lett. **79**, 572 (1997).
3. M. Kramer, arXiv:hep-ph/0106120.
4. E. Braaten and J. Lee, Phys. Rev D **63**, 071501 (2000).
5. A. A. Affolder *et al.* [CDF Collaboration], Phys. Rev. Lett. **85**, 2886 (2000). A. Abulencia *et al.* [CDF Collaboration], Phys. Rev. Lett. **99**, 132001 (2007).