A Measurement of the Prompt J/ψ Spin Alignment in CDF Run II Data

The CDF Collaboration

Abstract

We present a measurement of the spin alignment of promptly-produced J/ψ mesons having $5 \leq p_T < 30$ GeV/c and rapidity $|y| < 0.6$. Only J/ψ decays to $\mu^+\mu^-$ pairs with muon $p_T > 1.75$ GeV/c were used in this analysis, to match well with the GEANT-based CDF detector simulation. Promptly-produced events were distinguished from J/ψ mesons from heavy flavor decays by impact parameter requirements on the two muons. The data contain 151,553 J/ψ mesons with signal/background ratio of 13.9, taken with the Run II CMU Dimuon Triggers. The integrated luminosity was 188 ± 11 pb^{-1}. The analysis uses the same fitting methodology developed for the CDF Run I measurement. The new results show a negative (longitudinal) polarization at all p_T values, with some indication of an increase in the magnitude at larger p_T.

1 Introduction

One of the surprising results from the study of J/ψ meson production at the Tevatron in Run I was the large prompt production cross section [1]. A variety of theoretical models were developed to explain the anomalous production. One of the most promising schemes, based on non-relativistic QCD (NRQCD), used a color octet mechanism to augment color singlet production [2]. It predicted that the J/ψ mesons should be produced with transverse polarization, especially at large p_T. The first measurements were made with the Run I data [3]. The CDF II detector has a large dimuon acceptance, and systematic effects in the polarization measurement should be low. Production results have already been reported [4]. We set out to re-evaluate the Run I polarization measurements as a prelude to extending the p_T range of the measurements well beyond the Run I limit of 20 GeV/c.

2 Event Selection

The data were selected from runs taken between October 2002 and September 2003. The integrated luminosity is 188 ± 11 pb^{-1}. All runs used required the silicon vertex detector. The number of prompt J/ψ decays in this data set is about twice the size of the Run I sample with silicon.

The CDF II detector identifies muons using three separate tracking systems: the silicon vertex detector (SVX II), the central outer tracker (COT), and the muon detector. This analysis considers only muons in the CMU(P) fiducial region $|\eta| < 0.6$. The offline analysis took events having a $\mu^+\mu^-$ pair that satisfied the online trigger requirements and which fell within the J/ψ mass range of 2.7-3.5 GeV/c^2. The standard Run II track quality cuts were applied to the muon tracks. A 3-dimensional vertex fit (CTVMFT) is applied to the two muon tracks to reconstruct the J/ψ decay vertex.

Because of evidence of a data/simulation disagreement near the p_T threshold of 1.5 GeV/c from other analyses, we studied the muon p_T distribution from the simulation with the sideband-subtracted J/ψ decay muon p_T distribution from the data. For this comparison one must take into account the variation of the muon p_T distribution with polarization. Comparing data and simulation, we found excellent agreement (fit probability 55%) for all muon $p_T > 1.75$ GeV/c. The Run I muon p_T cut was 2.0 GeV/c or more. For good J/ψ acceptance with this muon p_T cut, we require that J/ψ $p_T > 5$ GeV/c. This gives a sample of 206,587 J/ψ mesons having $p_T > 5$ GeV/c and $|\ \eta\ | < 0.6$. The data fit uses a double Gaussian for the signal and a linear background shape starting at 2.74 GeV/c^2, shown in Fig. 1.

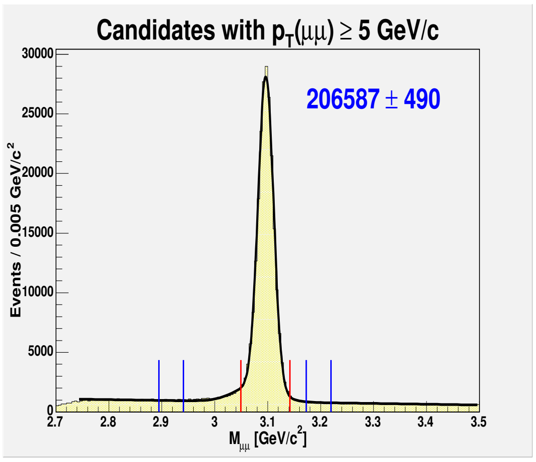

Figure 1: The invariant mass $M_{\mu\mu}$ distribution from vertex fit for the candidate events having $p_T(\mu\mu) \geq 5$ GeV/c

The dimuon trigger accepts J/ψ candidates both from prompt production and from B-hadron decays. We suppress the B-hadron contribution by cutting on the impact parameter significance of the two muons. We only accept events satisfying the following requirement:

$$\left(\frac{d_0(\mu^+)}{\sigma_{d_0(\mu^+)}}\right)^2 + \left(\frac{d_0(\mu^-)}{\sigma_{d_0(\mu^-)}}\right)^2 \leq 16. \tag{1}$$

This removes most of the long-lived background and gives a final J/ψ sample of 151,553 events. We divide these events into six J/ψ p_T ranges from 5-30 GeV/c for the polarization fit. The B-decay background varies from 3-8 % over the p_T

range. Using data before the impact parameter cut, we find that the fraction of J/ψ events from B-decay in this analysis agrees very well with the results of the Run II production paper [4]. The total event yield, extrapolated background yield, and B-contamination fraction in each J/ψ p_T bin are given in Table 1.

J/ψ p_T; mean	N_{ev}	N_B	f_B
5-6; 5.44	63665	4806	.032 $\pm$ .003
6-7; 6.44	39604	2647	.033 $\pm$ .004
7-9; 7.74	37794	2028	.048 $\pm$ .004
9-12; 9.97	15698	895	.039 $\pm$ .006
12-17; 13.36	4752	318	.083 $\pm$ .010
17-30; 19.12	879	103	.036 $\pm$ .024

Table 1: Total Data, Background, and Residual B Fraction in each p_T Bin.

3 Polarization Fit

The J/ψ decay alignment is given by the muon angular distribution in the J/ψ rest frame, expressed as a parameter α: dN/dcosθ^* $\propto 1 + \alpha \cos^2\theta^*$. Longitudinal alignment (α = -1) favors symmetric decays in the laboratory. Transverse alignment (α = +1) favors asymmetric decays, which have lower acceptance in CDF because the J/ψ acceptance and trigger efficiency depends on its alignment. These apparatus effects heavily modify the J/ψ decay angular distribution. As in the Run I analysis, these effects are handled here by making Monte Carlo templates of the angular distributions of fully-aligned J/ψ (longitudinal L and transverse T) decays. These templates represent the J/ψ cosθ^* distribution for 35 $\times 10^6$ generated events each for T and L samples after passing the GEANT-based CDF detector simulation package, the online trigger simulation and then the full offline reconstruction chain. The number of L events that survive is typically twice the number of T events because of acceptance cuts.

The polarization fit uses the χ^2 fitting routine from the Run I analysis [3]. In each J/ψ p_T bin, events in the J/ψ mass sideband regions above and below the signal region are binned in cosθ^* intervals of 0.05, defining the angular distribution of the background. The corresponding cosθ^* histogram for events in the signal region includes both this background distribution and the true J/ψ decay distribution. For each trial value of α in the fit process we normalize the templates to the total observed number of J/ψ signal events in a J/ψ p_T bin, then make a simultaneous χ^2 fit to the signal and background regions, as was done in Run I.

The fitter was tested against complete simulation data sets of size to match the signal and background fractions in the data. These simulation sets were made with known input polarization and were generated using the p_T spectrum measured in Run II. The fit results were in good agreement with the input values for all 6 pt bins for the two complete simulation experiments that were run. A toy Monte Carlo study with 160 experiments with α values from -1 to +1 events gave pull distributions consistent with a unit Gaussian and no offset. These studies confirmed the Run I checks on this fitter.

4 Results and Conclusions

The data listed in Table 1 were used in the fit described above. The fitted alignment parameter α includes effects from the residual B-decay contamination. We extracted the prompt polarization using the precise BaBar measurement of the polarization parameter α_B for inclusive B-meson decays, as adapted to hadron collider kinematics in the Run II production paper: α_B = -0.13 $\pm$ 0.01 [5]. Notice that this value is very similar to the overall polarization that we measure, so that the correction is small. We use the measured B-decay contamination fraction in each J/ψ p_T bin to correct the alignment parameter. The results are shown in Fig. 2 and tabulated in Table. 2.

J/ψ p_T [GeV/c]	N_{ev}	N_S	N_B	J/ψ polarization		
				$\alpha_{\rm fit}$	$\alpha_{\rm prompt}$	$\chi^2/d.o.f$
5.00 – 6.00	63665	58859	4806	$-0.145^{+0.061}_{-0.059}$	$-0.146^{+0.063}_{-0.061} \pm 0.005$	1.34
6.00 – 7.00	39604	36957	2647	$-0.105^{+0.063}_{-0.061}$	$-0.104^{+0.065}_{-0.063} \pm 0.005$	1.05
7.00 – 9.00	37794	35766	2028	$-0.146^{+0.049}_{-0.047}$	$-0.147^{+0.051}_{-0.049} \pm 0.005$	0.83
9.00 – 12.00	15698	14803	895	$-0.090^{+0.062}_{-0.059}$	$-0.088^{+0.065}_{-0.062} \pm 0.005$	0.89
12.00 – 17.00	4752	4434	318	$-0.222^{+0.088}_{-0.082}$	$-0.230^{+0.096}_{-0.089} \pm 0.005$	0.81
17.00 – 30.00	879	776	103	$-0.239^{+0.188}_{-0.165}$	$-0.243^{+0.195}_{-0.171} \pm 0.005$	1.14

Table 2: Summary of data and alignment parameter in J/ψ p_T bins.

The results depend only slightly on J/ψ p_T. In contrast to theoretical expectation, the polarization is negative, i.e., there is longitudinal alignment, over the entire p_T range. There is some indication that the alignment increases as p_T goes up.

As part of the systematic study, we looked at the polarization for different minimum p_T requirements on the muons. In all cases the J/ψ p_T threshold remained at 5 GeV/c. You can see from Fig. 3 that there are no systematic changes in the polarization, even when the muon p_T cut is lowered to 1.625 GeV/c.

Both Run I and Run II data tend to an increasingly negative polarization parameter as the J/ψ p_T increases. We are now in the process of including the full CDF Run II data set and set of muon systems in this analysis. We will also explore the ψ' polarization to present a complete picture of the polarization of prompt J/ψ mesons in 2 TeV $\overline{\rm p}$p collisions.

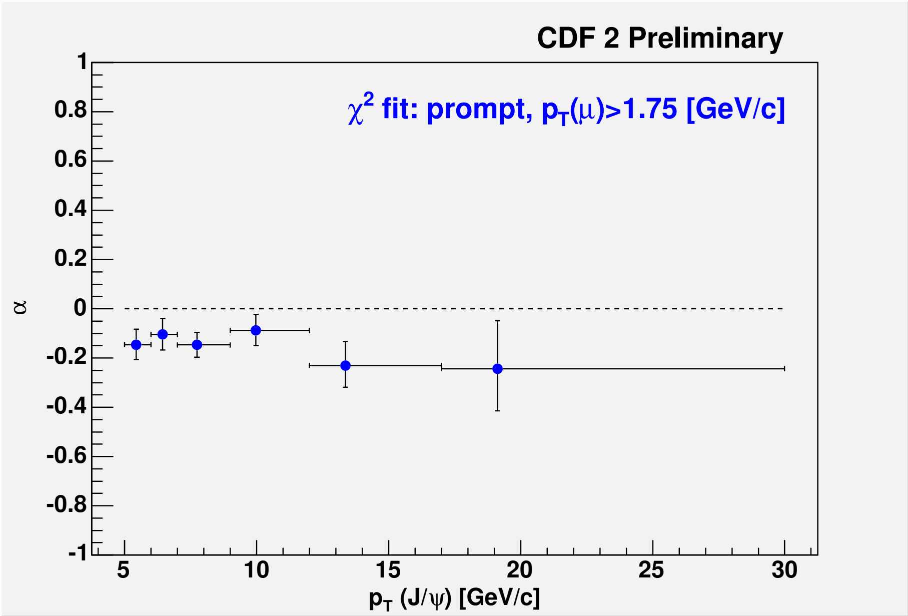

Figure 2: Alignment fit results to the data.

References

[1] CDF Collaboration, F. Abe, *et al.*, "J/ψ and $\psi(2S)$ Production in $\overline{\rm p}$p collisions at $\sqrt{s} = 1.8$ TeV," Phys. Rev. Lett. **79**,572 (1997).

[2] Eric Braaten and Sean Fleming, "Color-Octet Fragmentation and the ψ' Surplus at the Fermilab Tevatron," Phys. Rev. Lett. **74**,3327 (1995).

[3] CDF Collaboration, T. Affolder, *et al.*, "Measurement of J/ψ and $\psi(2S)$ Polarization in $\overline{\rm p}$p collisions at $\sqrt{s} = 1.8$ TeV," Phys. Rev. Lett. **85**,2886 (2000).

[4] CDF Collaboration, D. Acosta, *et al.*, "Measurement of the J/ψ Meson and b-Hadron Production Cross Sections in $\overline{\rm p}$p Collisions at $\sqrt{s} = 1960$ GeV," Phys. Rev. **D71**,032001 (2005).

[5] B. Aubert, *et al.*, "Study of inclusive production of charmonium mesons in B decay," Phys. Rev. **D67**,032002 (2003), hep-ex/0207097.

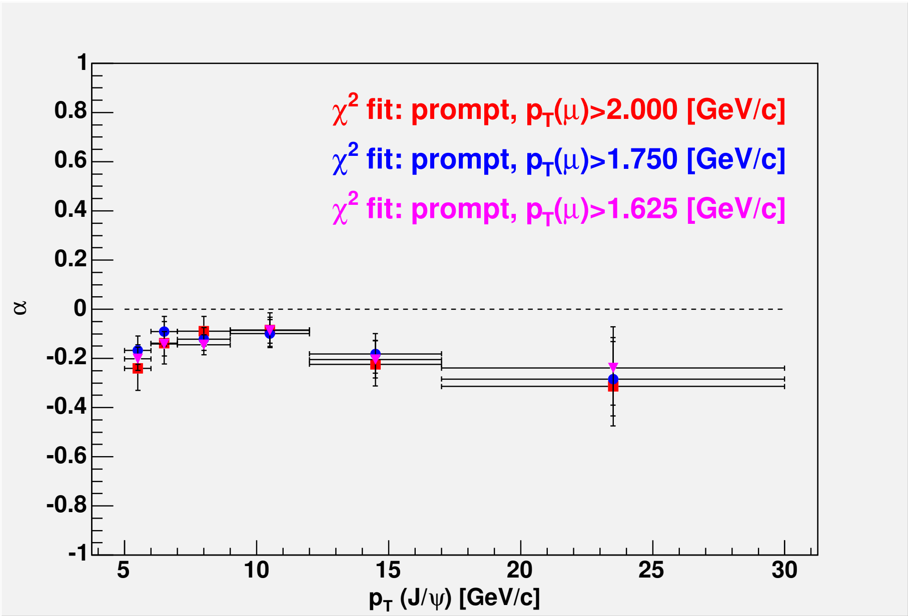

Figure 3: The polarization of prompt J/ψ with different minimum p_T requirements on muons.