

Υ Polarization at HERA-*B*

A. Kharchilava^a, T. Lohse^b, A. Somov^b, A. Tkabladze^{c1}

^a *Institute of Physics, Georgian Academy of Sciences, Tbilisi*

^b *Humboldt-University, Berlin, Germany*

^c *DESY Zeuthen, D-15738 Zeuthen, Germany*

Abstract

The production of Υ mesons in fixed target pN collisions is considered. It is shown that Non-Relativistic QCD predicts Υ states to be produced with sizeable transverse polarization. The possibility of a measurement of the Υ polarization at the HERA-*B* experiment is discussed.

PACS: 13.20.Gd, 13.88.+e, 13.60.Le, 12.38.Qk

¹Alexander von Humboldt Fellow

1 Introduction

The Factorization Approach (FA) based on the Non-Relativistic QCD (NRQCD) represents a reliable framework to study heavy quarkonium production and decay processes [1]. According to the FA the inclusive production cross section for a quarkonium state H in the process

$$A + B \rightarrow H + X \quad (1)$$

can be factorized as

$$\sigma(A + B \rightarrow H) = \sum_n \frac{F_n}{m_Q^{d_n-4}} \langle 0 | \mathcal{O}_n^H | 0 \rangle, \quad (2)$$

where the short-distance coefficients, F_n , are associated with the production of a heavy quark pair in the color and angular momentum state $[n]$. This part of the cross section involves only momenta at least of the order of the heavy quark mass, m_Q , and can be calculated perturbatively. Two distinct scales are introduced: the heavy quark-antiquark pair production process occurs at small distances, $1/(m_Q)$, and is factorized from the hadronization phase which takes place at large distances, $1/(m_Q v^2)$. Here v is the average velocity of heavy constituents in the quarkonium, with $v^2 \simeq 0.3$ for charmonium and $v^2 \simeq 0.1$ for bottomonium systems. The vacuum matrix elements of NRQCD operators, $\langle 0 | \mathcal{O}_n^H | 0 \rangle$, describe the evolution of the quark-antiquark state $[n]$ into the final hadronic state H [1]. These long distance matrix elements cannot be calculated perturbatively, but their relative importance in powers of velocity v can be estimated using the NRQCD velocity scaling rules [2]. The important feature of this formalism is that the cross section of heavy quarkonium production can be organized as double expansion in powers of v and $\alpha_s(m_Q)$. In higher order of v the FA implies that the quark-antiquark color octet intermediate states are allowed to contribute to heavy quarkonium production and decay processes.

Unlike the color singlet long distance matrix elements, each connected with the subsequent non-relativistic wave function at the origin, the color octet long distance matrix elements are unknown and have to be extracted from the experimental data. The NRQCD factorization approach implies universality, i.e. the values of long distance matrix elements extracted from different experimental data sets must be the same. However, due to the presently rather large theoretical uncertainties [3, 4] and the unknown size of higher twist process contributions [5] the existing experimental data do not allow yet to check the FA universality.

The data on direct J/ψ and ψ' production at large transverse momenta at the Tevatron indicates that the color octet contribution is dominating. The S state charmonia are produced through the gluon fragmentation into the $^3S_1^{(8)}$ octet state [6, 7]. Recent investigations have shown that the contribution of color octet states to the charmonium and bottomonium production cross sections is very important at fixed target energies, $\sqrt{s} \simeq 30 - 60$ GeV, and reduces existing discrepancies between experimental data and predictions of the Color Singlet Model (CSM) [8, 9]. However, some experimental data contradict the Color Octet Model (COM) predictions. In particular, theoretical predictions disagree with measurements of the polarization of J/ψ and ψ' particles produced at fixed target energies [9] and the COM predicts a too low relative yield of the χ_{c1} state compared to the χ_{c2} [9]. One possible solution of these discrepancies was proposed by Brodsky et al. [5] suggesting that higher twist processes, when more than one parton from projectile or target participates in the reaction, might give a significant contribution to low p_T production of J/ψ and χ_{c1} states. Problems exist also in charmonium photoproduction at HERA. The color octet contribution underestimates the inelastic J/ψ photoproduction cross section at large values of z ($z = E_{J/\psi}/E_\gamma$ in the laboratory frame) [10].

Spin effects in heavy quarkonia production are expected to provide tests for the different mechanisms of heavy quarkonium production [5, 4, 11, 12]. Predictions for the polarization of direct ψ 's produced at large p_T at the Tevatron are free from theoretical uncertainties connected with higher twist effects and corresponding measurements will provide an excellent possibility to test the NRQCD factorization approach. The observation of opposite sign double spin asymmetries in the production of different charmonium states can also be used to discriminate the NRQCD FA from the Color Evaporation Model (CEM) which predicts the same spin asymmetries for all charmonium states [11, 12]. The CEM also assumes a factorization between the production of a heavy quark pair and its hadronization phase. But unlike the NRQCD factorization approach the CEM postulates that multiple soft gluon exchange in the hadronization phase destroys the initial polarization of the heavy quark pair and the heavy quarkonium is produced unpolarized [13].

At the same time it is not excluded that the mass of the charm quark is not large enough to apply the NRQCD factorization approach to charmonium production and decay processes. Due to the rather large value of v^2 , about 0.3 for the charmonium system, the Fock states at higher order of v^2 may give the essential contribution and can then not be neglected. When fitting the values of the long distance parameters the heavy quark spin symmetries are used to reduce the number of independent parameters. These relations are valid up to v^2 and may get large corrections for charmonium production. In contrast, the NRQCD FA predictions for the bottomonium system are more reliable, since the expansion parameter v^2 is much smaller (around 0.1), than for the charmonium system. Higher twist processes are also expected to be suppressed as $\Lambda/m_b \simeq 0.1$ (compare with $\Lambda/m_c \simeq 0.3$). Also the QCD coupling constant is smaller for bottomonium system. Therefore, the characteristics of Υ meson production are more appropriate for a correct test of the NRQCD factorization approach.

In this article we consider the polarization of Υ mesons produced at fixed target energies. It will be shown that in the NRQCD factorization approach Υ mesons are produced transversely polarized, whereas the CEM predicts unpolarized bottomonium production. We present also numerical estimates of the projected statistical errors for the measurement of Υ polarization at the HERA-B experiment at DESY.

In the next section the bottomonium production in the various subprocesses is discussed. In section 3 the Υ polarization is calculated and numerical estimates for the expected Υ signal to background ratio as well as for the errors of the polarization measurement are considered in the section 4.

2 Υ Production Subprocesses and Matrix Elements.

In leading order in α_s the different S - and P -wave quark-antiquark states can be produced in the following $2 \rightarrow 2$ and $2 \rightarrow 3$ subprocesses:

- gluon-gluon fusion

$$\begin{aligned} gg &\rightarrow {}^1S_0^{(1,8)} & gg &\rightarrow {}^3S_1^{(1,8)} + g \\ gg &\rightarrow {}^3P_{0,2}^{(1,8)} & gg &\rightarrow {}^3P_1^{(1,8)} + g \end{aligned} \quad (3)$$

- gluon-quark scattering

$$gq \rightarrow {}^3S_1^{(8)} + q \quad gq \rightarrow {}^3P_1^{(1,8)} + q \quad (4)$$

- quark-antiquark annihilation

$$q\bar{q} \rightarrow {}^3S_1^{(8)} \quad (5)$$

where the superscripts (1,8) denote the color singlet and color octet states, respectively.

The total cross section of Υ production is given by the sum of direct production cross section and the cross section of χ_{bJ} states decaying through Υ mesons:

$$\sigma_{\Upsilon} = \sigma(\Upsilon)_{dir} + \sum_{J=0,1,2} Br(\chi_{bJ} \rightarrow \Upsilon X) \sigma(\chi_{bJ}) + \sum_{n=2,3} Br(\Upsilon(n) \rightarrow \Upsilon X) \sigma(\Upsilon(n)). \quad (6)$$

The production of each quarkonium state receives contributions from both color octet and color singlet states. The relative velocity for the bottomonium system is small, $v^2 \simeq 0.1$, and hence the production cross sections can be calculated with only the leading order color octet contribution taken into account.

In table I the color singlet and color octet long distance matrix elements for the production of χ_{bJ} states are presented. The values of matrix elements are taken from [9]. The color singlet matrix elements are computed from the wave functions of the Buchmüller-Tye potential tabulated in [14]. The matrix elements $\langle \mathcal{O}_8^H({}^3S_1) \rangle$ are fitted from the Tevatron data [7]. For the $3P$ bottomonium state the value of this matrix element is obtained by extrapolation from $1P$ and $2P$ states [9].

| Matrix Elements | $\chi_{b0}(1P)$ | $\chi_{b0}(2P)$ | $\chi_{b0}(3P)$ |
|--|---------------------|---------------------|-----------------|
| $\langle \mathcal{O}_1^H({}^3P_0) \rangle / m_b^2$ | $8.5 \cdot 10^{-2}$ | $9.9 \cdot 10^{-2}$ | 0.11 |
| $\langle \mathcal{O}_8^H({}^3S_1) \rangle$ | 0.42 | 0.32 | 0.25 |

Table I. Matrix elements for the P -wave bottomonia production in units GeV^3 .

The characteristics of Υ production at fixed target energies ($\sqrt{s} \simeq 40 \text{ GeV}$) differ from charmonium production, as it was mentioned in [9]. The $\Upsilon(nS)$ states are mainly produced in the quark-antiquark annihilation subprocess through decays of P wave states of bottomonia. Unlike J/ψ production, the color octet contribution to the Υ production in the gluon-gluon fusion subprocesses is less important. In leading order of perturbative QCD (pQCD) only ${}^1S_0^{(8)}$ and ${}^3P_J^{(8)}$ color octet states contribute to Υ production. They are suppressed as v^4 and v^2 compared to Υ production through color singlet 3S_1 and 3P_J states, respectively. Hence, due to the small value of $v^2 \simeq 0.1$, it turns out that in the gluon-gluon fusion subprocesses the main contribution to Υ production comes from the color singlet states. As can be seen from (3), the P -wave bottomonium states are produced in lowest order in pQCD expansion, $\mathcal{O}(\alpha_s^2)$. The subprocesses for direct production of S states ($\Upsilon(nS)$) are suppressed by the factor α_s/π compared to those for χ_{b0} and χ_{b2} production. Consequently, the indirect Υ meson fraction from the decay of χ_{bJ} states is expected to be large in the gluon-gluon fusion subprocesses.

The main contribution to P -wave bottomonia production comes from the quark-antiquark annihilation subprocess. First of all, the leading color octet and color singlet contributions to P -wave quarkonium production scale equally in v^2 , $\mathcal{O}(v^5)$, the subleading corrections being only of the order $\mathcal{O}(v^9)$. In leading order of v^2 , one color octet state contributes to the production of χ_{bJ} states, namely ${}^3S_1^{(8)}$. Moreover, in leading order of pQCD only this state is produced in the quark-antiquark annihilation subprocesses. The values of the matrix elements $\langle \mathcal{O}_8^{\chi_{bJ}}({}^3S_1) \rangle$ are larger as compared to the color singlet matrix elements for corresponding P states, connected to the quarkonium wave functions derivatives at the origin (see table I) [7]. Furthermore, at fixed

target energies the $q\bar{q}$ luminosity effectively increases compared to the gg luminosity due to the large mass of the $(b\bar{b})$ system.

The Υ production cross sections in gluon-gluon fusion and quark-antiquark annihilation subprocesses are presented in table II. The b -quark mass of $m_b = 4.9$ GeV is chosen as in ref. [7] in order to extract the values of color octet long distance parameters from the Tevatron data for the Υ production. The cross sections are calculated using the GRV LO parton distribution functions [15] evaluated at the factorization scale $Q^2 = 4m_b^2$. The long distance color octet parameters for direct $\Upsilon(nS)$ production are taken from [9]. For the decays of $\chi_{bJ}(3n)$ states² to $\Upsilon(3S)$ the same branching ratios are assumed as for the corresponding $n = 2$ states [9].

| subprocess | gluon-gluon fusion | | quark-antiquark annihilation through χ_{bJ} |
|--------------------|------------------------|---------------------|---|
| | through $\Upsilon(nS)$ | through χ_{bJ} | |
| $\sigma(\Upsilon)$ | 0.013 nb | 0.016 nb | 0.24 nb |

Table II. $\Upsilon(1S)$ production cross sections in different subprocesses.

From table II one finds that the direct Υ production cross section for the adopted values of the long distance parameters is more than one order of magnitude smaller than the total cross section. Even in the color singlet model the Υ mesons are mainly produced through decays of χ_{bJ} states. On the other hand, the color octet contribution seems to be dominant in χ_{bJ} production. The main contribution comes from the $^3S_1^{(8)}$ state, produced in quark-antiquark annihilation.

As was already shown in [9], the color octet contribution reduces the large discrepancy between the CSM prediction for the total Υ production cross section and experimental data [16, 17, 18]. Nevertheless, there remain large uncertainties due to contradicting experimental results. The cross sections obtained by integration of x_F distributions for $\Upsilon(1S)$ production presented in [16] and [17] are three and four times smaller, respectively, than the central value quoted in [18], 270 $pb/nucleon$. In addition, the theoretical value of the cross section strongly depends on the assumed mass of the b -quark. It is therefore impossible to extract the color octet matrix elements with reasonable accuracy from the fixed target bottomonia production data.

3 Υ Polarization

As it was already mentioned in [9], the measurement of the cross section for direct and indirect production of Υ 's would provide crucial information about the color octet mechanism, e.g., new constraints on the long distance color octet parameters would emerge. Such a measurement requires the reconstruction of χ_{bJ} states in the $\Upsilon + \gamma$ decay mode which is not a trivial task at fixed target experiments due to the small transverse momentum of the emitted photon.

Another possibility to check the NRQCD factorization approach is to measure the Υ polarization. In $H \rightarrow \ell^+\ell^-$ decays the polarization of S -state quarkonium is determined by the polar-angle distribution of its decay leptons with respect to the beam direction in the meson rest frame. Integrating over the azimuthal angle the distribution has the form

$$\frac{d\sigma}{d\cos\theta} \propto 1 + \alpha \cos^2\theta, \quad (7)$$

²As was suggested in [9], the large yield of the $\Upsilon(3S)$ state at the E772 experiment at FNAL [16] could be explained by assuming the unobserved $\chi_{bJ}(3P)$ states to lie below the open beauty threshold.

where θ is the angle between the positively charged lepton, ℓ^+ ($\ell = e, \mu$), and the beam axis in the quarkonium rest frame. The parameter α in the angular distribution can be related to ξ , the fraction of longitudinally polarized Υ mesons:

$$\alpha = \frac{1 - 3\xi}{1 + \xi} = \begin{cases} 1 & \text{for } \xi = 0 \\ -1 & \text{for } \xi = 1 \end{cases} \quad (8)$$

The calculation of J/ψ and ψ' polarization at fixed target energies and Tevatron collider energies was performed in [4, 9, 19, 20]. The most general method to calculate the cross sections for heavy quarkonium production with definite polarization within the NRQCD factorization approach was proposed by Braaten and Chen [21]. Tang and Vanttinen used the covariant projection method to calculate cross sections for polarized J/ψ and ψ' production [20]. The $\chi_{bJ}(nP)$ states are produced in quark-antiquark annihilation through only one color octet state, $^3S_1^{(8)}$. For this particular case both methods give the same result. We used the formulae derived in [20] to obtain the polarization of $\Upsilon(nS)$ states produced in cascade, $q\bar{q} \rightarrow ^3S_1^{(8)} \rightarrow \chi_{bJ} \rightarrow \Upsilon(nS) + \gamma$:

$$\begin{aligned} & \sigma(q\bar{q} \rightarrow b\bar{b}(^3S_1^{(8)}) \rightarrow \chi_{b1} + g \rightarrow \Upsilon + \gamma + g) \\ &= \frac{16\pi^3\alpha_s^2}{27M^5} \delta(1 - M^2/\hat{s}) Br(\chi_{1b} \rightarrow \Upsilon + \gamma) \langle \mathcal{O}_8^{\chi_{b1}}(^3S_1) \rangle \frac{3 - \delta_{\lambda 0}}{8}, \end{aligned} \quad (9)$$

$$\begin{aligned} & \sigma(q\bar{q} \rightarrow b\bar{b}(^3S_1^{(8)}) \rightarrow \chi_{b2} + g \rightarrow \Upsilon + \gamma + g) \\ &= \frac{16\pi^3\alpha_s^2}{27M^5} \delta(1 - M^2/\hat{s}) Br(\chi_{b2} \rightarrow \Upsilon + \gamma) \langle \mathcal{O}_8^{\chi_{b2}}(^3S_1) \rangle \frac{47 - 21\delta_{\lambda 0}}{120}. \end{aligned} \quad (10)$$

The scalar χ_{b0} state yields unpolarized bottomonium S -wave states. It follows from (9) and (10) that χ_{b1} and χ_{b2} intermediate states lead to values of $\alpha = 0.2$ and $\alpha = 0.29$, respectively. Taking into account all transitions from $\chi_{bJ}(1P)$ and $\chi_{bJ}(2P)$ states to $\Upsilon(1S)$ we obtain for the polarization parameter in quark-antiquark annihilation subprocess

$$\alpha \simeq 0.24. \quad (11)$$

This result remains practically unchanged if we add contribution from $\chi_{bJ}(3P)$ states with the same branching ratios as for the corresponding $2P$ states. It is worth mentioning that the value $\alpha \simeq 0.24$ represents only a lower theoretical limit for the polarization. This value is calculated taking into account only the quark-antiquark annihilation subprocesses. In gluon-gluon fusion subprocesses the polarization of Υ mesons is larger due to the dominant contribution from χ_{b2} decays which yield pure transverse polarization [5]. For the values of octet long distance parameters (table I) the size of the polarization is $\alpha \simeq 0.3$ and hence also exceeds 0.24. However, large uncertainties in color octet long distance parameters for P -wave bottomonia does not allow to compute the relative importance of the various subprocesses, so that the lower bound of $\alpha = 0.24$ remains as the only firm prediction.

In contrast to charmonium production the higher twist effects for the bottomonium system are expected to be small. In particular, the higher twist effect suggested in [5], when more than one parton from the projectile or target is involved in the heavy quarkonium states production, is expected to be negligible for Υ production. Two partons should be within a transverse distance of $O(1/m_Q)$ in order to interact with the other parton and to produce a heavy quark-antiquark bound state. Consequently, such a higher twist process is suppressed by a factor of $O(\Lambda_{QCD}^2/m_Q^2)$

[5]. To explain the discrepancies between the CSM predictions and measured relative production rate χ_{c1}/χ_{c2} it is suggested that the above suppression can be compensated by a kinematical enhancement [5]. Thus the χ_{c1} production cross section in the higher twist process is expected to be at the same level as the χ_{c2} production cross section from gluon-gluon fusion subprocesses. In bottomonium production such a mechanism is suppressed by the mass of the bottom quark $O(\Lambda_{QCD}^2/m_b^2)$, i.e. the corresponding cross section should be one order of magnitude smaller than in the charmonium case. The effect of the kinematical enhancement is also smaller due to the larger mass of the bottomonium system. Moreover, as can be seen from table II, the gluon-gluon fusion subprocesses give small contributions to Υ production at fixed target energies compared to J/ψ production. Therefore, the measurement of Υ polarization at fixed target energies will allow to distinguish between the NRQCD approach and the CEM, which predicts unpolarized production of all bottomonium states.

4 Expectations for HERA-B

HERA-B is an experiment presently set up at DESY which uses the HERA 920 GeV/c proton beam incident on various nuclear targets [22]. Being optimized for the study of the various aspects of B -physics, i.g. the measurement of the CP asymmetry in the $B_d^0 \rightarrow J/\psi K_S^0$ decays, the experiment is well suited to perform accurate Υ polarization measurements due to the following reasons:

- large acceptance of the apparatus (polar angle coverage in the laboratory frame from 10 mrad up to 250 mrad),
- good momentum/mass resolution which allows to separate the $\Upsilon(nS)$ states,
- high statistics due to high interaction rates (40 MHz).

In the current analysis the acceptance for Υ production and the mass resolution in the Υ mass region are determined using a detailed HERA-B detector simulation [23]. The Υ mesons are generated with the PYTHIA 5.7 event generator [24] and then processed through the simulation of the full detector. The cross sections for Υ production are taken from the measurements of the E605 experiment ($\sqrt{s} \simeq 38.8$ GeV) [17]:

$$\begin{aligned} Br \frac{d\sigma}{dy}|_{y=0}(\Upsilon(1S) + \Upsilon(2S) + \Upsilon(3S)) &= 2.31 \text{ pb/nucleon}; \\ \frac{Br \frac{d\sigma}{dy}(\Upsilon(2S))}{Br \frac{d\sigma}{dy}(\Upsilon(1S))} &= 0.31; \quad \frac{Br \frac{d\sigma}{dy}(\Upsilon(3S))}{Br \frac{d\sigma}{dy}(\Upsilon(1S))} = 0.09. \end{aligned} \quad (12)$$

As it was noted above (in section 2), this experiment gives the lowest lying value for the Υ production cross section, about 130 pb/nucleon for $\sigma(\Upsilon(1S) + \Upsilon(2S) + \Upsilon(3S))$.

In the following only the muonic decay channel is considered because the expected mass resolution is better. Figure 1 shows the $\Upsilon \rightarrow \mu^+\mu^-$ mass distributions on top of the Drell-Yan pair production expected in one year ($10^7 s$) of HERA-B running with 40 MHz interactions rate. Cut on the muon momenta, $p > 5$ GeV/c and $p_T > 0.5$ GeV/c, are applied to satisfy the trigger requirements. The expected statistics are about 10000 fully reconstructed Υ events per year. The background is largely dominated by the Drell-Yan process. It is simulated by PYTHIA with the cross section calculated at the leading order, thus a K factor of 2.3 is taken into account according to [17]. As can be seen from Fig.1 the predicted mass resolution of about 1% and a signal to background ratio $S/B \simeq 1.3$ (in a $\pm 2\sigma$ mass window around the $\Upsilon(1S)$) allows to clearly observe the Υ mass peaks above the background and to separate the $\Upsilon(1S)$ and $\Upsilon(2S)$ states.

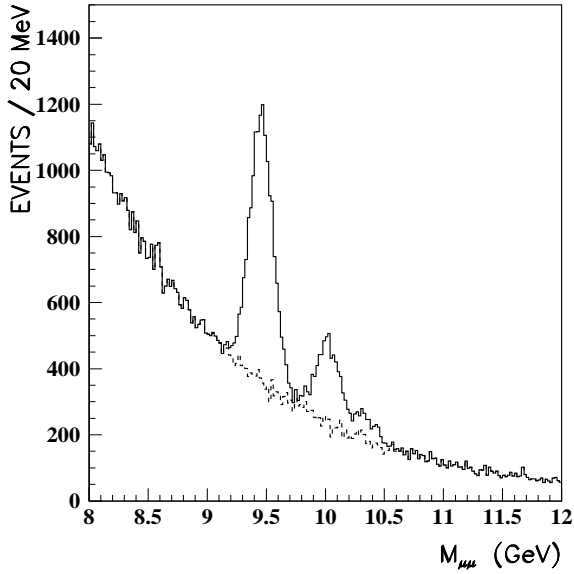


Figure 1: $\Upsilon \rightarrow \mu^+\mu^-$ mass distribution in one year running of HERA-B

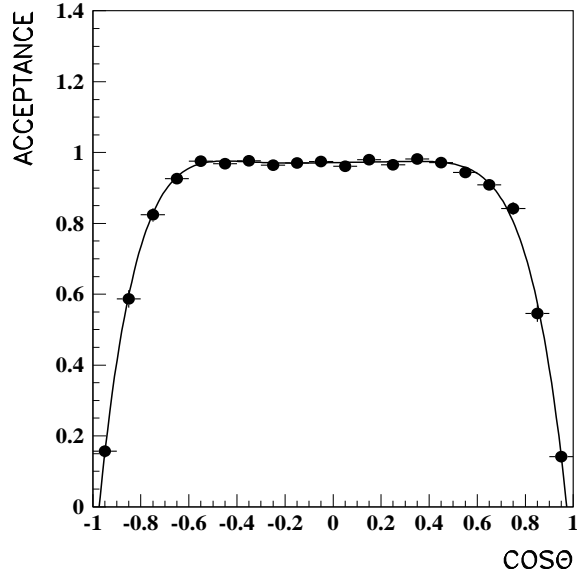


Figure 2: Acceptance for the Υ events as a function of the CMS polar angle

Figure 2 shows the acceptance for Υ events as a function of the cosine of the polar angle between the positive muon momentum and the beam direction in the rest frame of Υ . In almost the full range of $\cos \theta$ the acceptance is close to unity. Large acceptance corrections are expected only for $|\cos \theta| > 0.8$.

The accuracy of the polarization measurement is estimated by simulating various initial polarizations for Υ mesons and Drell-Yan pairs with various signal to background ratios. After corrections for the acceptance the resulting angular distributions are fitted with the function:

$$\frac{dN}{d\cos\theta} = S(1 + \alpha \cos^2\theta) + B(1 + \alpha' \cos^2\theta). \quad (13)$$

Here S and B are signal and background normalization factors and α and α' determine corresponding polarization parameters. This procedure allows to extract the polarization not only of Υ mesons but also of the Drell-Yan pair, which is an interesting issue by itself. Assuming that Drell-Yan polarization and signal to background ratio could be precisely measured in the HERA-B experiment, the number of free parameters in the fitting function is reduced to 2. Results on the parameter α obtained from the fit for the different MC input values and for 10000 reconstructed Υ events are shown in table III.

| Input values of α | S/B=1.3 | | S/B=1 | S/B=2 |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|
| | $\alpha' = 0$ | $\alpha' = 1$ | $\alpha' = 1$ | |
| $\alpha = 0.25$ | 0.21 ± 0.08 | 0.21 ± 0.08 | 0.22 ± 0.09 | 0.23 ± 0.08 |
| $\alpha = 0.5$ | 0.52 ± 0.10 | 0.48 ± 0.09 | 0.51 ± 0.09 | 0.54 ± 0.09 |
| $\alpha = 1$ | 0.91 ± 0.12 | 0.96 ± 0.11 | 0.96 ± 0.12 | 0.98 ± 0.10 |

Table III. Parameter α obtained from the fit for different MC input values.

We note that the expected statistical error on α is largely dominated by the Υ statistics rather than by the value of the background polarization and the signal to background ratio. Figure 3 illustrates the statistical error $\delta\alpha$ as a function of the number of reconstructed Υ events

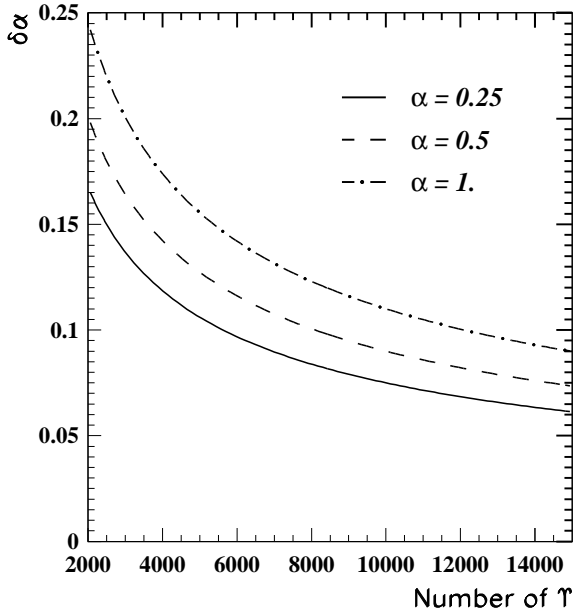


Figure 3: Attainable accuracy in α for $\alpha = 0.25, 0.5$ and 1 vs. the number of the reconstructed Υ events. $S/B=1.3$

for various α 's. As can be seen, an accuracy on the polarization parameter $\delta\alpha \simeq 0.08$ for $\alpha = 0.25$ can be achieved for one year of the HERA- B running. The expected error will allow to distinguish between $\alpha = 0$ (CEM) and $\alpha \simeq 0.24 - 0.3$ (NRQCD FA) with a 3σ significance.

5 Conclusions

The polarization of Υ mesons is calculated at fixed target energies ($\sqrt{s} \simeq 40$ GeV). It is shown that in the NRQCD factorization approach Υ mesons are expected to be produced transversely polarized; the parameter α for the polar angle distribution of quarkonium decay products is about $0.24 \div 0.3$. In contrast, the color evaporation model postulates that multiple soft gluon exchange in the hadronization phase destroys the initial polarization of the heavy quark pair and quarkonium is produced unpolarized.

Higher twist effects are expected to be small due to the large mass of the b -quark. The contribution of higher Fock states in bottomonium production are more suppressed than in the charmonium case, the relative velocity for the bottomonium family is about $v^2 \simeq 0.1$. Thus the measurement of the Υ polarization provides an excellent opportunity to test different mechanisms of heavy quarkonium production. In particular, it allows to distinguish between the NRQCD FA [1] and the CEM [13]. On the other side, the observation of an extremely large polarization will indicate that Υ mesons are mainly produced through color singlet states and that the color octet parameters for χ_{bJ} production extracted from the Tevatron data should be much smaller than known at present.

The Monte Carlo simulation shows that the projected statistical error for the measurement of the polarization parameter α is about 0.08 for $\alpha \simeq 0.25$ in one year running of the HERA- B experiment. The simulation is done only for the $\mu^+\mu^-$ decay channel. A statistics gain of almost a factor 2 is expected from the e^+e^- channel. The simulation conservatively assume the lowest value for the Υ production cross section measured in different experiments [16, 17, 18] at $\sqrt{s} \simeq 38.8$ GeV which corresponds to a HERA proton beam momentum of 800 GeV/c (the current value for HERA is 920 GeV/c).

Acknowledgments

We are grateful to S. Brodsky, R. Mankel and M. Vanttinen for useful comments and discussions. We thank W.-D. Nowak for helpful comments and careful reading of this manuscript. A.T. acknowledges the support by the Alexander von Humboldt Foundation. A.S. is grateful to the DFG financial support (III GK - GRK 271/1).

References

- [1] G.T. Bodwin, E. Braaten, and G.P. Lepage, Phys. Rev. **D51** (1995) 1125.
- [2] G.P. Lepage, L. Magnea, C. Nakhleh, U. Magnea, and K. Hornbostel, Phys. Rev. **D46** (1992) 4052.
- [3] M. Mangano and A. Petrelli, Int. J. Mod. Phys. **A12** (1997) 3887,
M. Beneke, in 'Proceedings of the Second Workshop on Continuous Advances in QCD',
Minneapolis, M. Polikarpov (ed.), World Scientific, Singapore, 1996, p. 12.
P. Ernström, L. Lönnblad, and M. Vanttinen, Z. Phys. **C76** (1997) 515.
M. Beneke, I.Z. Rothstein, and Mark B. Wise, Phys. Lett. **B408** (1997) 373.
- [4] M. Beneke and M. Krämer, Phys. Rev. **D55** (1997) 5269.
- [5] M. Vanttinen, P. Hoyer, S.J. Brodsky, and W.-K. Tang, Phys. Rev. **D51** (1995) 3332.
- [6] E. Braaten and S. Fleming, Phys. Rev. Lett. **74** (1995) 3327.
- [7] P. Cho and A.K. Leibovich, Phys.Rev. **D53** (1996) 150,
P. Cho and A.K. Leibovich, Phys.Rev. **D53** (1996) 6203.
- [8] S. Gupta and K. Sridhar, TIFR/TH/96-04, hep-ph/9601349.
W.-K. Tang and M. Vanttinen, Phys. Rev. **D54** (1996) 4349.
L. Slepchenko and A. Tkabladze, in proceedings of 3rd German-Russian Workshop on
'Progress in Heavy Quark Physics', Dubna, 20-22 May 1996, hep-ph/9608296 (1996).
- [9] M. Beneke and I.Z. Rothstein, Phys. Rev. **D54** (1996) 2005,
M. Beneke, CERN-TH/97-55, hep-ph/9703429.
- [10] M. Cacciari and M. Krämer, Phys.Rev.Lett. **76** (1996) 4128.
- [11] O. Teryaev and A. Tkabladze, Phys. Rev **56** (1997) 7331.
- [12] W.-D. Nowak and A Tkabladze, DESY 98-139, hep-ph/9809413 (1998).
- [13] H. Fritzsch, Phys. Lett. **B67** (1977) 217,
F. Halzen, Phys. Lett. **B69** (1977) 105.
- [14] E.J. Eichten and C. Quigg, Phys. Rev. **D52** (1995) 1726.
- [15] M. Glück, E. Reya, and A. Vogt, Z.Phys. **C67** (1995) 433.
- [16] D.M. Alde *et al.*, Phys. Rev. Lett. **66** (1991) 2285.
- [17] T. Yoshida *et al.*, Phys. Rev. **D39** (1989) 3516,
G. Moreno *et al.*, Phys. Rev. **D43** (1991) 2815.
- [18] T. Alexopoulos *et al.*, Phys. Lett. **B374** (1996) 271.
- [19] M. Beneke and I.Z. Rothstein, Phys. Lett. **B372** (1996) 157.
- [20] W.-K. Tang and M. Vanttinen, Phys. Rev. **D54** (1996) 4349.
- [21] E. Braaten and Y.-Q. Chen, Phys. Rev. **D54** (1996) 3216.
- [22] T. Lohse *et al.*, An Experiment to Study CP Violation in the B System Using an Internal
Target at the HERA Proton Ring (Proposal), DESY-PRC 94/02 (1994).
- [23] S. Nowak, *HBGEAN and HBRCAN*, HERA-B Internal Note (1995).
- [24] T. Sjöstrand, Computer Physics Commun. **82** (1994) 74.