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Sivers Asymmetry in J/ψ Production in COMPASS 2010 Proton Data

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Abstract. The Sivers asymmetry in J/ψ production in scattering of muons off transversely polarized protons $\mu^+ p^\uparrow \rightarrow \mu^+ + J/\psi + X$ is measured in two $z$-bins (inclusive and exclusive production) in the COMPASS 2010 data. Only J/ψ’s decaying into muons are detected. About 2 230 and 4 450 J/ψ events in the lower and the higher $z$-bins are found. The Sivers asymmetry is extracted using a simple double-ratio method and is found to be compatible with zero in the lower $z$ bin and to have a slight preference for negative values in the higher $z$ bin.

1. Introduction
The gluon Sivers function is related to the orbital motion of gluons in a transversely polarized nucleon. One of the cleanest ways of accessing it is the measurement of the Sivers asymmetry (see Sec. 4) of hadrons, produced in the scattering of leptons off transversely polarized nucleons $l + p^\uparrow \rightarrow l + h + X$ via the Photon-Gluon Fusion (PGF) process $\gamma g \rightarrow q\bar{q}$. When the $q\bar{q}$ is $c\bar{c}$ (or $b\bar{b}$), the leading process $\gamma q \rightarrow q$ as well as the QCD Compton process $\gamma q \rightarrow qg$ are suppressed and the PGF dominates. This is best ensured in the open-charm (beauty) production [1, 2]. Another way of enhancing the PGF contribution is to select high-$p_T$ hadron pairs [3]. This method was applied recently on COMPASS to measure the gluon Sivers asymmetry [4, 5]. Finally, the third way to the PGF is charmonium production [6, 7].

In this article results of the third method, applied to the COMPASS data collected in 2010, are discussed. In 2010 COMPASS used 160 GeV/c muon beam and transversely polarized proton target. For that case the process of interest is

$$\mu^+ + p^\uparrow \rightarrow \mu^+ + J/\psi + X.$$ (1)

The J/ψ is identified when it decays into muons (using a peak in $\mu^+\mu^-$ invariant mass distribution), so $2\mu^+ + \mu^- + X$ is looked for in the final state. Since the dominant mechanism of the J/ψ production can be different for the inclusive and exclusive cases, we study the reaction in two $z$-intervals$^1$ [0.3, 0.95] and [0.95, 1.05].

2. Event selection
Good quality of the selected events was ensured using standard COMPASS criteria on tracks and primary vertex reconstruction confidence levels, primary vertex position and beam muon

$^1$ Fraction of the available energy carried out by the J/ψ: $z \equiv \frac{E_{J/\psi}}{E_{-E'}}$. Practically no events are found for $z < 0.3$. 

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momentum. Outgoing muon tracks are identified using their ability to penetrate through a thick material. They are required to cross at least 30 radiation lengths in the spectrometer and to have associated hits in a detector behind the first muon filter.

Events with extra outgoing muons apart from $2\mu^+1\mu^-$ are rejected. After the quality cuts and this cut there are 480,726 events left. There is no way to efficiently distinguish the $\mu^+$ coming from the $J/\psi$ decay and the scattered beam $\mu^+$, so both possible combinations are examined.

For each combination the invariant mass $M_{\mu\mu}$ is checked to be in $[2.999, 3.239]$ GeV/$c^2$, which we call the signal band.

In the signal band there are 8,026 events (2,744 and 5,282 for the inclusive and exclusive bins respectively). Background level in the signal band was calculated (separately for the two $z$-bins) fitting an invariant mass histogram with function

$$A \frac{N(M_{\mu\mu}, \mu, \sigma)}{w} + B(M_{\mu\mu})^C,$$

where $N(x, \mu, \sigma)$ is the normal distribution, $w$ is the bin width and $A$, $\mu$, $\sigma$, $B$ and $C$ are the fit parameters (the signal band approximately corresponds to $\mu \pm 2\sigma$). The signal to background ratios are 4.31 and 5.25, resulting in about 2,230 and 4,450 signal events in the lower (inclusive) and the higher (exclusive) $z$-bin respectively.

For purposes of background estimation two side-bands were defined as $M_{\mu\mu} \in [2.579, 2.939] \cup [3.299, 3.659]$ GeV/$c^2$. There are 1,865 and 2,919 events in the side-bands for the two $z$-bins. The invariant mass distributions together with the fits and the boundaries of the signal band and of the side-bands are shown on Fig. 1 and 2.

**Figure 1.** Dimuon invariant mass for $z \in [0.3, 0.95]$ (inclusive bin).

**Figure 2.** Dimuon invariant mass for $z \in [0.95, 1.05]$ (exclusive bin).

### 3. Kinematic Distributions

In this section we show selected kinematic distributions with all cuts applied (except cuts on the depicted variable, if there are any). The plots contain data from all data-taking periods of 2010 combined. Backgrounds were subtracted using distribution shapes in the side-bands.

The majority of the events lie in the area of low Bjorken $x$ and low momentum transfer $Q^2$ (Fig. 3). The exclusivity of the produced $J/\psi$ can be seen on Fig. 4, showing the 2 $z$-bins, and Fig. 5, showing the energy of the undetected system $E_{\text{miss}} = (M_{J/\psi}^2 - M_{\rho}^2)/(2M_{\rho})$.

The Fig. 6 shows the rapidity $y_R$ of the $J/\psi$ in the $\mu\rho$ center of mass system. R. M. Godbole et al. [6] give a formula for the gluon $x$ in their model: $x_{g_{\text{model}}} = \frac{M_{J/\psi}}{\sqrt{s}}e^{-y_R}$ (Fig. 7).
Figure 3. The Bjorken $x$ and the $Q^2$ are correlated due to the kinematics. Both are low.

Figure 4. The variable $z$.

The vertical red lines denote the bin boundaries.

Figure 5. Energy of the undetected system for all events and for the two bins.

Figure 6. Rapidity of the $J/\psi$ in the $\mu p$ center of mass system.

Figure 7. In the model of R. M. Godbole et al. [6] $s^{-1/2} M_{J/\psi} e^{-y_R}$ is the gluon $x$.

4. Asymmetry Evaluation

The Sivers asymmetry is an amplitude of a sin $\phi_{\text{Siv}}$ modulation of the cross-section. The Sivers angle is defined as $\phi_{\text{Siv}} = \phi_h - \phi_S$, that is the difference between the azimuthal angles of the $J/\psi$ momentum and the target polarization.

For this initial study we use a simple double ratio method to evaluate the asymmetry (similar to e.g. [8]). The upstream and downstream cells of the 3-cell target are combined to form an "outer cell". The 2010 run is divided into 12 periods, each consisting of two sub-periods with opposite polarization of the target cells. In each period the double ratio of counts in the 2 cells, 2 sub-periods and in 8 bins in $\phi_{\text{Siv}}$ is calculated

$$A_{\text{Siv}}(\phi_{\text{Siv}}) = \frac{N_{\text{out}}(\phi_{\text{Siv}}) N_{\text{cent}}^{\uparrow \downarrow}(\phi_{\text{Siv}})}{N_{\text{out}}^{\uparrow \downarrow}(\phi_{\text{Siv}}) N_{\text{cent}}(\phi_{\text{Siv}})}.$$  \hspace{1cm} (3)

A “raw” Sivers asymmetry $A_{\text{Siv}}^{\text{raw}}$ is obtained by fit $A_{\text{Siv}}(\phi_{\text{Siv}}) = C[1 + 4 A_{\text{Siv}}^{\text{raw}} \sin(\phi_{\text{Siv}})]$. It is done period by period to minimize an impact of possible changes in the data-taking conditions. The error-weighted mean of $A_{\text{Siv}}^{\text{raw}}$’s from all subperiods is used in the following.

One can assume that the measured asymmetry $A_{\text{Siv}}^{\text{raw}}$ gets contribution from the real asymmetry $A_{\text{Siv}}^{\text{raw}}|_{\text{sig}}$ and a possible asymmetry of the background $A_{\text{Siv}}^{\text{raw}}|_{\text{bg}}$ weighted by the ratios of counts (determined from the signal to background ratios)

$$A_{\text{Siv}} = \frac{N_{\text{sig}}}{N_{\text{tot}}} A_{\text{Siv}}^{\text{raw}}|_{\text{sig}} + \frac{N_{\text{bg}}}{N_{\text{tot}}} A_{\text{Siv}}^{\text{raw}}|_{\text{bg}}.$$  \hspace{1cm} (4)
If we assume that $A_{\text{Siv}}^\text{raw}|_{bg}$ equals the asymmetry measured in the side-bands (Sec. 2), we can subtract it using the equation (4). The effect of subtraction is small (Tab. 1), because of the large event to background ratio.

### Table 1. The raw asymmetries and the final asymmetries.

<table>
<thead>
<tr>
<th>$z \in [0.3, 0.95]$</th>
<th>$z \in [0.95, 1.05]$</th>
<th>$z \in [0.3, 0.95]$</th>
<th>$z \in [0.95, 1.05]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{\text{Siv}}^\text{raw}$</td>
<td>$A_{\text{Siv}}^\text{raw}$</td>
<td>$A_{\text{Siv}}$</td>
<td>$A_{\text{Siv}}$</td>
</tr>
<tr>
<td>$\sigma_A$</td>
<td>$\sigma_A$</td>
<td>$\sigma_A$</td>
<td>$\sigma_A$</td>
</tr>
<tr>
<td>Signal band</td>
<td>$-0.010$</td>
<td>$0.031$</td>
<td>$-0.034$</td>
</tr>
<tr>
<td>Side bands</td>
<td>$-0.025$</td>
<td>$0.031$</td>
<td>$-0.030$</td>
</tr>
<tr>
<td>Background subtracted</td>
<td>$-0.006$</td>
<td>$0.039$</td>
<td>$-0.034$</td>
</tr>
<tr>
<td>$z \in [0.3, 0.95]$</td>
<td>$-0.045$</td>
<td>$0.033$</td>
<td>$-0.28$</td>
</tr>
<tr>
<td>$z \in [0.95, 1.05]$</td>
<td>$-0.050$</td>
<td>$0.33$</td>
<td></td>
</tr>
</tbody>
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The actual Sivers asymmetry is obtained from the raw one by division by the average target polarization $P = 80\%$ and the dilution factor $f = 0.15$, which takes into account the fraction of polarizable nuclei in the target material. The final results are shown in Tab. 1 and on Fig. 8.

![Figure 8. The final Sivers asymmetry.](image)

### 5. Conclusion and Outlook

In the whole 2010 run data, 2 230 and 4 450 $J/\psi$ events in the lower (inclusive) and the higher (exclusive) $z$-bins are found. The statistics is small, because of rareness of the process. The Sivers asymmetry, extracted in this initial study by a simple double-ratio method, is found to be compatible with zero in the lower $z$ bin and to have a slight preference for negative values in the higher $z$ bin.

A future improvement could be made utilizing the unbinned maximum likelihood asymmetry extraction method, which is well suited for small data samples. Also, a simple Monte Carlo simulation testing whether the measured $x_g|_{\text{model}}$ distribution is compatible with the model [6] would be an interesting continuation of this study. Finally, looking at all the COMPASS transverse data would increase the statistics, but at most by a factor of 2.

### References