Drell-Yan Pairs, $W^\pm$ and $Z^0$ Event Rates and Background at RHIC

A. A. Derevschikov$^1$, V. L. Rykov$^{1,2}$, K. E. Shestermanov$^1$ and A. Yokosawa$^3$

Abstract. The estimates for the Drell-Yan pairs, $W^\pm$ and $Z^0$ acceptances and event rates in the STAR and PHENIX detectors at RHIC are presented. The background to $W^\pm$ in STAR evaluated. The results were obtained by Monte-Carlo simulations with the PYTHIA/JETSET and GEANT programs.

Introduction

The measurements of Drell-Yan lepton pairs, $W^\pm$ and $Z^0$ production in polarized proton collisions appear to be the only way to determine polarization properties of the sea quarks. Moreover, the intermediate bosons are produced due to the parity violating mechanism providing an unique opportunity to study a parity violation effects in the hard hadron interactions. All these phenomena have been discussed in details elsewhere (see, for example, (1-4)), and a quintessence of these discussions is reflected in the Proposal on Spin Physics at RHIC (5).

In this report we provide the event rate estimations (6) for the processes above for the two major detectors, STAR and PHENIX. We also present the first results of the background study for the $W^\pm$ detection in STAR (7). All data were obtained by Monte-Carlo simulations with the PYTHIA/JETSET and GEANT V3.15 programs. The EHLQ1 (8) set of proton structure functions has been used. The parameters for PYTHIA were tuned up in order to produce results in a reasonable agreement with the available experimental data from E772, ISR, UA1, UA2 and CDF (see (6) and references therein).

Figure 1: Differential Drell-Yan pairs production cross section in \(pp\) collisions (a) and STAR and PHENIX acceptances (b).

**Acceptances and Event Rates**

The differential cross sections for Drell-Yan pairs production at \(\sqrt{s} = 200\) and 500 GeV are shown in Fig. 1a. For \(W^\pm\) and \(Z^0\), it has been assumed that only lepton decay modes are detected, i.e. one high \(p_T\) lepton, for \(W^\pm \rightarrow l^\pm \nu_l\), and two high \(p_T\) leptons, for \(Z^0 \rightarrow l^+l^-\), where \(l^\pm\) are either electron or muon. *PYTHIA V5.6* provides the following estimates for \(W^\pm\) and \(Z^0\) production cross sections in \(pp\) interactions at \(\sqrt{s} = 500\) GeV:

\[
\begin{align*}
\sigma \cdot B(pp \rightarrow W^+ + X \rightarrow l^+\nu_l + X) &= 120 \text{ pb}; \\
\sigma \cdot B(pp \rightarrow W^- + X \rightarrow l^-\bar{\nu}_l + X) &= 43 \text{ pb}; \\
\sigma \cdot B(pp \rightarrow Z^0 + X \rightarrow l^+l^- + X) &= 10 \text{ pb}.
\end{align*}
\]

The integrated luminosity, during the exposition time of \(4 \cdot 10^6\) seconds (100 days, 50% efficiency), has been taken as:

- At \(\sqrt{s} = 500\) GeV, \(\int L dt = 800 \text{ pb}^{-1}\) \((L = 2 \cdot 10^{32} \text{ cm}^{-2} \cdot \text{sec}^{-1})\);
- At \(\sqrt{s} = 200\) GeV, \(\int L dt = 320 \text{ pb}^{-1}\) \((L = 8 \cdot 10^{31} \text{ cm}^{-2} \cdot \text{sec}^{-1})\).

The STAR and PHENIX setups had been described elsewhere (9,10). Here we considered six geometries for the detection single leptons and lepton pairs:

- **STAR\_b:** STAR detector with the Barrel Electromagnetic Calorimeter (EMC) of the acceptance (fiducial): \(-0.95 < \eta < 0.95\) and \(2\pi\) coverage in \(\phi\);
- **STAR\_b1ec:** STAR detector with the Barrel + one End Cup EMC of the acceptance (fiducial): \(-0.95 < \eta < 1.9\) and \(2\pi\) coverage in \(\phi\);
- **STAR\_b2ec:** STAR detector with the Barrel + two End Cup EMC of the acceptance (fiducial): \(-1.9 < \eta < 1.9\) and \(2\pi\) coverage in \(\phi\);
- **PHENIX\_1\mu:** PHENIX one-arm muon detector of the summary acceptance (geometry): \(1.1 < \eta < 2.5\) and \(2\pi\) coverage in \(\phi\);
- **PHENIX\_2\mu:** PHENIX two-arm muon detector of the summary acceptance...
Table 1: Drell-Yan pairs event rates, integrated over mass intervals $M_1 < M_{t+1} < M_2$, at $\sqrt{s} = 200 \text{GeV}$ for $\int L dt = 320 \text{pb}^{-1}$; Cuts: $P_T^\mu > 4 \text{GeV}/c$ or $E_\mu > 2 \text{GeV}$.

<table>
<thead>
<tr>
<th>$M_1 - M_2, \text{GeV}/c^2$</th>
<th>2-5</th>
<th>5-9</th>
<th>9-12</th>
<th>12-15</th>
<th>15-20</th>
<th>20-25</th>
<th>2-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAR.b</td>
<td>550</td>
<td>11,500</td>
<td>7,200</td>
<td>2,900</td>
<td>1,800</td>
<td>600</td>
<td>24,500</td>
</tr>
<tr>
<td>STAR.b1ec</td>
<td>800</td>
<td>19,000</td>
<td>13,000</td>
<td>5,400</td>
<td>3,400</td>
<td>1,100</td>
<td>43,000</td>
</tr>
<tr>
<td>STAR.b2ec</td>
<td>1,000</td>
<td>27,000</td>
<td>19,000</td>
<td>8,100</td>
<td>5,100</td>
<td>1,700</td>
<td>62,000</td>
</tr>
<tr>
<td>PHENIX.1µ</td>
<td>95,000</td>
<td>19,400</td>
<td>2,600</td>
<td>850</td>
<td>360</td>
<td>60</td>
<td>118,000</td>
</tr>
<tr>
<td>PHENIX.2µ</td>
<td>190,000</td>
<td>41,000</td>
<td>6,300</td>
<td>2,100</td>
<td>1,000</td>
<td>200</td>
<td>240,000</td>
</tr>
<tr>
<td>PHENIX.µ</td>
<td>-</td>
<td>450</td>
<td>260</td>
<td>110</td>
<td>70</td>
<td>25</td>
<td>915</td>
</tr>
</tbody>
</table>

Table 2: The same as Table 1, but at $\sqrt{s} = 500 \text{GeV}$ for $\int L dt = 800 \text{pb}^{-1}$; Cuts: $P_T^\mu > 5 \text{GeV}/c$ or $E_\mu > 2 \text{GeV}$.

<table>
<thead>
<tr>
<th>$M_1 - M_2, \text{GeV}/c^2$</th>
<th>2-5</th>
<th>5-9</th>
<th>9-12</th>
<th>12-15</th>
<th>15-20</th>
<th>20-25</th>
<th>2-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAR.b</td>
<td>500</td>
<td>12,000</td>
<td>21,000</td>
<td>12,300</td>
<td>9,000</td>
<td>3,800</td>
<td>59,000</td>
</tr>
<tr>
<td>STAR.b1ec</td>
<td>600</td>
<td>21,500</td>
<td>37,000</td>
<td>23,500</td>
<td>17,500</td>
<td>7,300</td>
<td>107,000</td>
</tr>
<tr>
<td>STAR.b2ec</td>
<td>660</td>
<td>31,000</td>
<td>53,000</td>
<td>35,000</td>
<td>27,000</td>
<td>11,300</td>
<td>107,000</td>
</tr>
<tr>
<td>PHENIX.1µ</td>
<td>235,000</td>
<td>67,500</td>
<td>14,000</td>
<td>6,200</td>
<td>4,100</td>
<td>1,400</td>
<td>328,000</td>
</tr>
<tr>
<td>PHENIX.2µ</td>
<td>470,000</td>
<td>140,000</td>
<td>30,000</td>
<td>14,000</td>
<td>9,500</td>
<td>3,500</td>
<td>670,000</td>
</tr>
<tr>
<td>PHENIX.µ</td>
<td>-</td>
<td>600</td>
<td>900</td>
<td>430</td>
<td>340</td>
<td>140</td>
<td>2,400</td>
</tr>
</tbody>
</table>

(geometries): $1.1 < \eta < 2.5$ plus $-2.5 < \eta < -1.1$ with $2\pi$ coverage in $\varphi$; $\text{PHENIX.µ}$: PHENIX EMC, consisting of two separated segments of the acceptance (geometry): $-0.35 < \eta < 0.35$ with the coverage in $\varphi$: $-112.5^\circ < \varphi < -22.5^\circ$ and $22.5^\circ < \varphi < 112.5^\circ$.

The STAR and PHENIX acceptances to the Drell-Yan pairs are shown in Fig. 1b. Besides geometries, the thresholds to the lepton energies $E_l$ and/or transverse momenta $P_T$, which are supposed to be applied at the lowest trigger levels, have also been taken into account. The expected event rates are presented in Tables 1 and 2.

One can observe, PHENIX.µ covers well the low pair mass region, while STAR is more sensitive to the higher mass di-electrons. The sensitivities, in terms of the "hardness" of the primary hard-colliding proton constituents producing detected lepton pair, are shown in Fig. 2. PHENIX.µ acquires better muon pairs, originated from the hard interaction of quark with high $x_q$ but of rather soft antiquark, while STAR has a better sensitivity to the antiquark sea with the higher $x_{\overline{q}}$.

The expected event rates for $W^\pm$ and $Z^0$ are shown in Table 3. Apparently, $Z^0$ is almost unreachable in PHENIX due to its low acceptance to the high mass dilepton pairs. High background level in the forward and backward directions might also make difficult to detect $W^\pm \rightarrow \mu \nu$ signal with the PHENIX.µ setups.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
Background for $W^\pm$ in STAR

Any event with a high, local energy deposition in the EMC, matching a high-$P_T$ charged particle, and observed in the tracking system, may be considered a potential candidate for a $W^\pm$ decay. Other sources can also provide such a signature, however, for example: $Z^0$ decays with one missing electron; electrons from $\pi^0$ Dalitz decays; misidentified high-$P_T$ charged hadrons as electrons; overlapping in the EMC $\gamma$-quanta from $\pi^0$ decays with charged high $P_T$ hadrons.

For the STAR barrel EMC the background from $Z^0 \to e^+e^-$, with one electron missing, is expected to be quite low: $\sim 2.5\%$ for $W^+$, and about 10% for $W^-$. With the end cup(s), this background will be even lower due to a better detection efficiency to electron pairs.

The $P_T$ spectrum of $e^\pm$ originated from $\pi^0 \to \gamma e^+e^-$ Dalitz decays drops rapidly when $P_T$ increases (2,7). As a result, with the only requirement being $P_T^{e^\pm} > 20 - 25$ GeV/c, the background from Dalitz pairs will be reduced to about the same level or even lower than from $Z^0$ decays.

Table 3: $W^\pm$ and $Z^0$ event rates at $\sqrt{s} = 500$ GeV for $\int L \ dt = 800$ pb$^{-1}$; Cuts: $P_T^{e^\pm} > 20$ GeV/c.
The contamination of the $W^\pm$ event samples by high-$P_T$ charged hadrons misidentified as electrons is expected to be the most serious source of background. A number of the STAR detector features can be used to separate charged hadrons from electrons in order to get a necessary rejection power of $\sim 10^3$.

At the lowest trigger level a threshold $\sim 20 - 25$ GeV/c should be applied to the $P_T^\pm$. Since hadrons mostly deposit only a fraction of their energy in the EM calorimeter, a single hadron will effectively be "seen" in the EMC as a particle with a lower $P_T$ than it actually is. Thus, due to the rapid drop of the hadron $P_T$ spectrum when $P_T$ increases, it effectively provides a hadron $P_T$ spectrum, measured in the EMC, lying well below the actual one. The effective hadron suppression power of this mechanism varies from about 50 to 150 in the $P_T$ region of $10 - 50$ GeV/c. Some other selection criteria, common for the practice of other collider experiments, also have been studied (isolation cut; limit to the shower width, defined with the fine-grained Shower Maximum Detector placed at the depth 5 - $X_0$ in the EMC).

The results of simulations are shown in Fig. 3, providing that the $W^+$ signal can be extracted in STAR-b at the background level of $\sim 3 - 7\%$, while the detection efficiency, due to applying cuts, drops by $\sim 15 - 25\%$. Background to $W^-$ can be rejected to the level of $\sim 10 - 30\%$, depending on the selection criteria.

Conclusion

The estimated event rates prove the possibility for STAR and PHENIX to carry out the substantial spin physics with Drell-Yan pairs, $W^\pm$ and $Z^0$ at the statistical error level of a few percents, provided the polarization of colliding protons is $\sim 50 - 70\%$. The background to the $W^\pm$ signal in STAR is expected to be at the acceptable level.
Acknowledgments

We are pleased to express our appreciation to G. Bunce, D. Grosnick, S. Heppellmann, Yo. Makdisi, S. Nurushev, J. Soffer, H. Spinka, M. Tannenbaum, A. Vasiliev and D. Underwood for the useful and encouraging discussions.

References

1. Bourrely, C. and Soffer, J., *Parton Distributions and Parity-Violating Asymmetries in $W^\pm$ and $Z^0$ Production at RHIC*, CPT-93/P.2865, CNRS Luminy (France).