Report to the SPIN-94 Symposium
Indiana University Cyclotron Facility
Bloomington, IN 47408, USA

STAR Note #210

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]

[1] *Experimental Physics Division, Institute of High Energy Physics, Protvino, Moscow District 142284, Russia*
[2] *Department of Physics and Astronomy, Wayne State University, Detroit, Michigan 48202, USA*
[3] *High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

September, 1994

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 referencies therein).

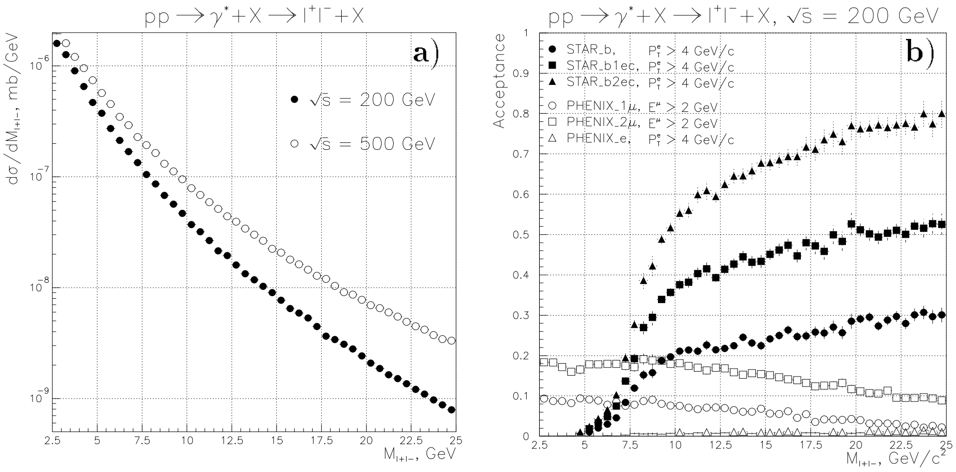

Figure 1: Differential Drell-Yan pairs production cross section in pp collisions (**a**) and STAR and PHENIX acceptances (**b**).

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 $W^{\pm} \to l^{\pm}\nu$, and two high P_T leptons, for $Z^0 \to l^+l^-$, 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 $\sqrt{s} = 500\,GeV$:

$$\sigma \cdot B(pp \to W^+ + X \to l^+\nu_l + X) = \mathbf{120}\ \text{pb};$$
$$\sigma \cdot B(pp \to W^- + X \to l^-\overline{\nu}_l + X) = \mathbf{43}\ \text{pb};$$
$$\sigma \cdot B(pp \to Z^0 + X \to l^+l^- + X) = \mathbf{10}\ \text{pb}.$$

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

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

The STAR and PHENIX setups had been described elsewere (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 2π coverage in φ;

STAR_b1ec: STAR detector with the Barrel + one End Cup EMC of the acceptance (fiducial): $-0.95 < \eta < 1.9$ and 2π coverage in φ;

STAR_b2ec: STAR detector with the Barrel + two End Cup EMC of the acceptance (fiducial): $-1.9 < \eta < 1.9$ and 2π coverage in φ;

PHENIX_1μ: PHENIX one-arm muon detector of the summary acceptance (geometry): $1.1 < \eta < 2.5$ and 2π coverage in φ;

PHENIX_2μ: PHENIX two-arm muon detector of the summary acceptance (geometry): $1.1 < \eta < 2.5$ plus $-2.5 < \eta < -1.1$ with 2π coverage in φ;

Table 1: Drell-Yan pairs event rates, integrated over mass intervals $M_1 < M_{l^+l^-} < M_2$, at $\sqrt{s} = 200\,GeV$ for $\int L\,dt = 320\,pb^{-1}$; Cuts: $P_T^e > 4\,GeV/c$ or $E_\mu > 2\,GeV$.

$M_1 - M_2$, GeV/c^2	2–5	5–9	9–12	12–15	15–20	20–25	2–25
STAR_b	550	11,500	7,200	2,900	1,800	600	24,500
STAR_b1ec	800	19,000	13,000	5,400	3,400	1,100	43,000
STAR_b2ec	1,000	27,000	19,000	8,100	5,100	1,700	62,000
PHENIX_1μ	95,000	19,400	2,600	850	360	60	118,000
PHENIX_2μ	190,000	41,000	6,300	2,100	1,000	200	240,000
PHENIX_e	–	450	260	110	70	25	915

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

$M_1 - M_2$, GeV/c^2	2–5	5–9	9–12	12–15	15–20	20–25	2–25
STAR_b	500	12,000	21,000	12,300	9,000	3,800	59,000
STAR_b1ec	600	21,500	37,000	23,500	17,500	7,300	107,000
STAR_b2ec	660	31,000	53,000	35,000	27,000	11,300	107,000
PHENIX_1μ	235,000	67,500	14,000	6,200	4,100	1,400	328,000
PHENIX_2μ	470,000	140,000	30,000	14,000	9,500	3,500	670,000
PHENIX_e	–	600	900	430	340	140	2,400

PHENIX_e: PHENIX EMC, consisting of two separated segments of the acceptance (geometry): $-0.35 < \eta < 0.35$ with the coverage in φ: $-112.5^o < \varphi < -22.5^o$ and $22.5^o < \varphi < 112.5^o$.

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[1]. High background level in the forward and backward directions might also make difficult to detect $W^\pm \to \mu\nu$ signal with the PHENIX_μ setups.

[1]J. Moss pointed out that the requirement $P_T^\mu > 20\,GeV/c$ might not be necessary for background suppression in PHENIX_μ. Without P_T^μ-cut the event rate for PHENIX_1μ remains unchanged compared to the Table 3, but for PHENIX_2μ it increases from 310 to 700 events.

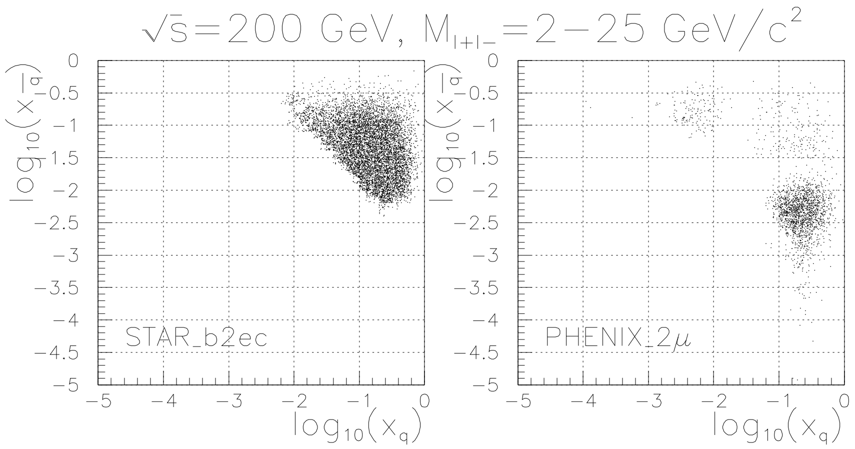

Figure 2: The x_q vs $x_{\overline{q}}$ plot of the primary constituents, producing lepton pairs within STAR_b2ec and PHENIX_2μ acceptances.

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 π^0 Dalitz decays; misidentified high-P_T charged hadrons as electrons; overlapping in the EMC γ-quanta from π^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: ~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 $P_T^e > 20 - 25\ GeV/c$, 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: $P_T^{e,\mu} > 20\,GeV/c$.

	STAR_b	STAR_b1ec	STAR_b2ec	PHENIX_1μ	PHENIX_2μ	PHENIX_e
W^+	64,600	71,500	78,400	4,650	9,300	14,900
W^-	15,000	20,600	26,200	5,050	10,100	2,600
Z^0	2,700	4,200	6,200	25	310	120

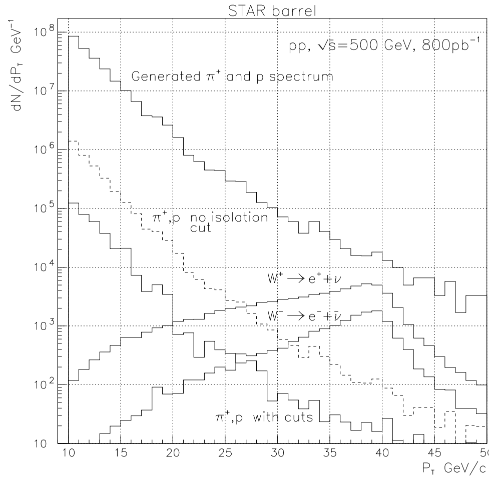

Figure 3: Charged hadron background vs P_T before and after applying rejection criteria along with $e^{\pm}$ from $W^{\pm}$ decays.

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 ∼20 - 25 GeV/c should be applied to the $P_T^{e^{\pm}}$. 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-graned Shower Maximum Detector placed at the depth $5 \cdot X_0$ 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 ∼3-7%, while the detection efficiency, due to applying cuts, drops by ∼15-25%. Background to W^- can be rejected to the level of ∼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 ∼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.

The work of A.A.D. and V.L.R. was supported in part by the U.S. Department of Energy, Division of Basic Energy Sciences under Contract no. DE-AC02-76CH00016 and also (V.L.R.) by the U.S. Department of Energy, Grant DE-FG0292ER40713. The work of K.E.S. and A.Y. was supported in part by the U.S. Department of Energy, Division of High Energy Physics, Contract W-31-109-ENG-38.

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