

On background study for MMT-Drell-Yan process at SPD (NICA) energy.

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Abstract.

MMT-DY process in case of polarized beams at SPD may allow to measure the full set of leading TMDs and provide an access to GPDs, thus is of great interest to study at NICA. But this process is always accompanied with a huge background. Minimum-bias background, as the most strong one, together with some QCD processes, were simulated by use of PYTHIA6.4 Monte Carlo generator and compared to the signal process at the case of proton-proton beams with $E_{cm} = 27$ GeV. The processes were considered in the two regions of muon pair invariant mass. The set of criteria for background discrimination is proposed. The efficiencies of these criteria are estimated.

1. Introduction

The plans to study Drell-Yan (DY) [1] process, which was first independently described by Matveev, Muradyan and Tavkhelidze (MMT) [2], at SPD (Spin Physics Detector) at NICA collider are the first in the list of physics proposal at SPD facility [3]. This process of the di-lepton production in hadron-hadron collisions is playing an important role in the studies of hadron structure and with transverse polarized hadrons at SPD allows to measure the full set of leading TMDs.

The measurements of DY processes using various beams and targets have started in 1970 with the non-polarized proton beam of AGS at accelerator in Brookhaven. From that time set of DY experiments were performed at FNAL and CERN but only two of them were directly connected with studies of the nucleon structure - NA51 [4] and E866.

Present list of the DY experiment in the world (polarized COMPASS-II at CERN [5], non-polarized E-906 at FNAL and non-polarized PANDA [6] at FAIR) includes fixed target and collider experiments aimed to study spin-dependent and spin-independent processes in a wide range of energies. Physics goals of the experiments include studies of one or several TMD PDFs. Future collider DY experiments are included in the long range programs of the PHENIX and STAR at RHIC.

The Spin Physics Detector (SPD) experiment, proposed at the second intersection point of the NICA collider, will have a number of advantages for DY measurements related to nucleon structure studies [3]. These advantages include: - operations with pp, pd and dd beams; - scan of effects on beam energies; - measurements of effects via muon and electron-positron pairs simultaneously; - operations with non-polarized, transverse and longitudinally polarized beams or their combinations. Such possibilities permit for the first time to perform comprehensive



studies of all leading twist PDFs of nucleons in a single experiment with minimum systematic errors.

2. Backgrounds to MMT-DY process

In our study we have simulated MMT-DY process and the backgrounds (10^9) events to this process by using PYTHIA6.4 [11] Monte-Carlo generator for the case of centre of mass energy of colliding proton-proton unpolarized beams $E_{c.m.} = 27$ GeV. We assume the highest Luminosity $L = 1 \cdot 10^{32} \text{cm}^{-2} \text{s}^{-1}$ and the full year of beam operation. At this conditions we expect up to 3.1×10^7 Drell-Yan events per year (in a whole spectrum of a lepton pair invariant mass). In this paper we consider only muon pairs production case.

One of the most strong source of the background for MMT-DY lepton pairs are the leptons produced in the minimum-bias (low - P_T production, single and double diffractive scattering) events and in a set of QCD subprocesses (mainly $q + g \rightarrow q + g$, $g + g \rightarrow g + g$ and $q + q' \rightarrow q + q'$ subprocesses), where the possibility of appearance of two (and more) leptons in the final state is very high. According to PYTHIA the total cross section of these processes $\sigma_{tot}^{bkg} = 32.9$ mb which is about 10^7 times higher than the cross section of the signal MMT-DY subprocess $q + \bar{q} \rightarrow \gamma^* \rightarrow l^+ + l^-$: $\sigma_{qq \rightarrow l^+ l^-} = 9.2 \cdot 10^{-6} \text{mb}$.

During our simulation we allow mesons to decay (and produce muons) in the volume before Muon (Range) System: cylinder radius $R = 2400$ mm, size from the centre along Z axis $L = 4000$ mm and we do search for muons in the angle region $3^\circ < \Theta < 177^\circ$.

The distribution of the number (per year) of parents of selected (positive) muons produced in background minimum-bias and QCD events is presented in Fig.1. It is seen that the main contribution comes from π^\pm - and K^\pm -meson decays. The most probable grandparents of background muons - are string (Lund model), ρ^0 , ρ^+ , K_S^0 , K^{*0} , K^+ , η' - mesons.

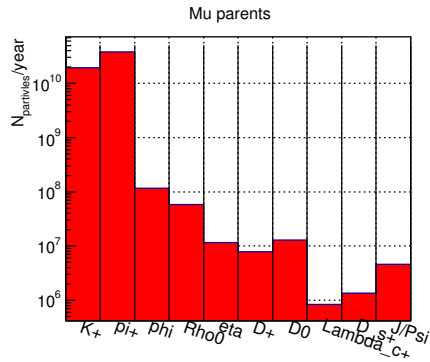


Figure 1. Number of parents of selected (positive) muons produced in background minimum-bias and QCD events.

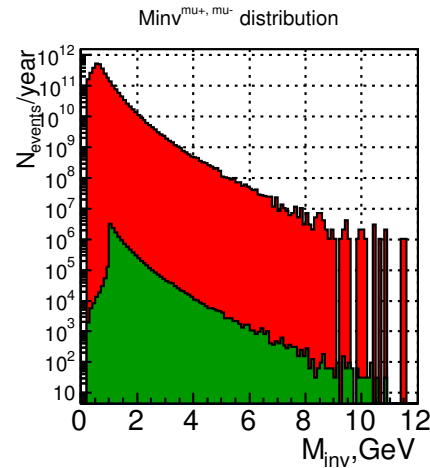


Figure 2. The invariant mass of final-state $\mu^+ \mu^-$ pair $M_{inv}^{\mu^+ \mu^-}$.

Fig.2 shows the distribution of the muon pair invariant mass. By the red color denoted background, by green - signal process. It is clearly seen that one of the possible criterion for background suppression would be the cut on this variable. The most effective one would be in the region of $M_{inv}^{\mu^+ \mu^-} < 0.9 - 1$ GeV. Further increase of $M_{inv}^{\mu^+ \mu^-}$ cut has no sense for Minimum-bias background events (it leads to significant loss of signal events without real improvement of S/B ratio), but may have sense in order to avoid backgrounds in the regions of J/Ψ and other resonances production.

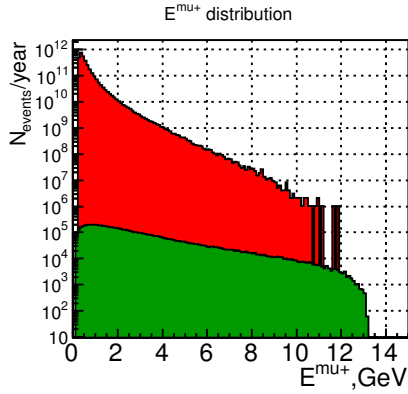


Figure 3. Muon energy $E^{\mu+}$ spectrum.

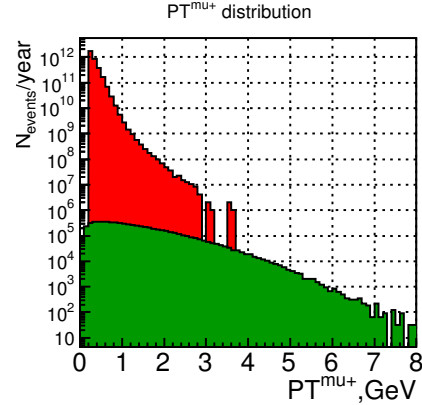


Figure 4. Muon transverse momentum $PT^{\mu+}$ spectrum.

Fig.3 and 4 present distributions of muon energy $E^{\mu+}$ and transverse momentum $PT^{\mu+}$ correspondingly. As before by the red color denoted background, by green - signal process. One can see that these variables can also be used for signal and background separation. It is seen that the most effective cut on $E(P)$ would only be in the region $E_{bkg}^{\mu} < 1-2$ GeV where the gradient in background E_{bkg}^{μ} distribution is big and not so big in the signal one. The most effective cuts for transverse momentum could also be in the region $PT_{bkg}^{\mu} < 1.5$ GeV.

Thus for background suppression we propose the next cuts:

- 1. We choose events with exactly 2 muons in the final state with $E(P)^{\mu} > 1.0$ GeV, $PT^{\mu} > 0.6$ GeV;
- 2. These muons should have the opposite charges;
- 3. Muon pair invariant mass is $M_{inv}^{\mu^+\mu^-} > 1$ GeV ($M_{inv}^{\mu^+\mu^-} > 4$ GeV);
- 4. Transverse momentum of the leading μ (with the highest E) $PT_{Emax}^{\mu} > 1.5$ GeV;
- 5. Muons are isolated, i.e. the summarized energy of the final state charged particles within the cone around the axes of the muons movement of the radius $R_{isolation} = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = 0.2$ (η — pseudorapidity, φ — azimuthal angle) $E_{sum} < 0.5$ GeV (for more details see [6], [7], [8], [9], [10]);
- 6. Their production vertex lies within the distance from the interaction point < 1 mm.

The Tables 1 and 2 below show dependence of signal to background ratio (S/B) on application of the chosen six cuts (and their different combinations) for two cases of muon pair invariant mass ($M_{inv}^{\mu^+\mu^-} > 1$ GeV and $M_{inv}^{\mu^+\mu^-} > 4$ GeV correspondingly). Efficiencies of these cuts defined both for signal and background as $\text{Eff}(K,N) = \text{Nev}(\text{cut}N) / \text{Nev}(\text{cut}K)$ (where K, N stands for the numbers of the cuts, Nev - number of survived after the corresponding cut events). Second region $M_{inv}^{\mu^+\mu^-} > 4$ GeV is supposed to have much lower contribution from additional backgrounds (except Υ -states), while the first one $M_{inv}^{\mu^+\mu^-} > 1$ GeV includes also significant backgrounds from charmonia, J/Ψ and Ψ' production, which should be studied separately. The backgrounds from b-quarks (which is negligible) and charmonia most likely can be suppressed by the isolation criteria, while regions of J/Ψ and Ψ' most likely should be excluded from consideration according to their widths.

These results of backgrounds study are very preliminary because they are done for the case of “ideal” detector without account of detector material and magnetic field. But they give us

Table 1. Influence of the proposed cuts on S/B separation in case of $M_{inv}(\mu^+\mu^-) > 1 \text{ GeV}$.

N of cut	S/B ratio	Efficiency for BKG	Remainder of of BKG	Efficiency for SIG	Remainder of of SIG
1	0.002	Eff(1,init) 19204	$5.2 \cdot 10^{-3} \%$	2.68	37.0 %
2 ⁺¹	0.003	Eff(2,1) 1.73	$3.0 \cdot 10^{-3} \%$	1.01	36.9 %
3 ⁺²⁺¹	0.004	Eff(3,2) 1.21	$2.5 \cdot 10^{-3} \%$	1.01	36.5 %
4 ⁺³⁺²⁺¹	0.054	Eff(4,3) 20.1	$1.2 \cdot 10^{-4} \%$	1.58	23.1 %
5 ⁺³⁺²⁺¹	34.0	Eff(5,3) 8285	$3.0 \cdot 10^{-7} \%$	1.04	35.2 %
6 ⁺³⁺²⁺¹	2.94	Eff(6,3) 690	$3.6 \cdot 10^{-6} \%$	1.00	36.5 %
7=5 ⁺⁴⁺³⁺²⁺¹	> 64	Eff(7,3) > 24860	$< 1.0 \cdot 10^{-7} \%$	1.65	22.0 %

Table 2. Influence of the proposed cuts on S/B separation in case of $M_{inv}(\mu^+\mu^-) > 4 \text{ GeV}$.

N of cut	S/B ratio	Efficiency for BKG	Remainder of of BKG	Efficiency for SIG	Remainder of of SIG
1	$3.8 \cdot 10^{-5}$	Eff(1,init) 19277	$5.2 \cdot 10^{-3} \%$	1.5	66 %
2 ⁺¹	$6.6 \cdot 10^{-5}$	Eff(2,1) 1.72	$3.0 \cdot 10^{-3} \%$	1.0	66 %
3 ⁺²⁺¹	$8.1 \cdot 10^{-5}$	Eff(3,2) 1.21	$2.5 \cdot 10^{-3} \%$	1.0	66 %
4 ⁺³⁺²⁺¹	$1.7 \cdot 10^{-3}$	Eff(4,3) 20.8	$1.2 \cdot 10^{-4} \%$	1.0	66 %
5 ⁺³⁺²⁺¹	0.286	Eff(5,3) 3545	$7.0 \cdot 10^{-7} \%$	1.0	66 %
6 ⁺³⁺²⁺¹	$4.5 \cdot 10^{-2}$	Eff(6,3) 564	$3.6 \cdot 10^{-6} \%$	1.0	66 %
7=5 ⁺⁴⁺³⁺²⁺¹	> 2	Eff(7,3) > 24813	$< 1.0 \cdot 10^{-7} \%$	1.0	66 %

hope of possibility of background suppression up to sufficient level. More precise study with a higher statistics will be done using the SPDRoot simulation.

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