The study of backgrounds in direct photon production at SPD NICA energies

Исследование фоновых процессов в рождении прямых фотонов при энергиях SPD NICA

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В данной работе мы исследуем соотношение сигнальных и основных фоновых событий для совместного с J/ψ мезонами и прямого рождения фотонов при энергиях коллайдера NICA с помощью Монте-Карло генератора PYTHIA8. Мы извлекаем ряд кинематических ограничений, позволяющих улучшить отношения сигнал/фон. Мы сравниваем результаты моделирования спектров прямых фотонов и π^0 мезонов в различных интервалах p_T и x_F с экспериментальными данными, и представляем предсказания для отношения сигнал/фон к рождению прямых фотонов при энергии NICA $\sqrt{s} = 27$ ГэВ.

In this paper we study the signal-to-background ratios for the J/ψ-meson associated and direct photon main production processes at the energies of SPD NICA experiment using the Monte Carlo generator PYTHIA8. We extract the set of kinematic constraints allowing to improve signal-to-background ratios. We compare the results of our simulation for the direct photon spectra in different intervals of p_T и x_F with the experimental data and present the predictions for signal-to-background ratios in direct photon production at the NICA energy of $\sqrt{s} = 27$ GeV.

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Introduction

The direct photon production in proton-proton collisions, both inclusive and heavy-quarkonium-associated, is an important source of information on gluon distributions inside the proton, including spin gluon content [1–4]. Its study is the important task of the physical program at Spin Physics Detector (SPD) [5] at NICA Collider [6]. We consider direct photons as photons produced in the processes of hard scattering of partons from initial protons. At first we simulate associated production of J/ψ-mesons and photons using PYTHIA8 [7] Monte Carlo (MC) event generator for a signal and background events, accounting the real experimental restrictions [5].

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Photon associated J/ψ-meson production

The signal process we consider is $g + g \to J/\psi(3S_1^{(1)}) + \gamma$ where the J/ψ meson is identified by its decay channel $J/\psi \to \mu^-\mu^+$. We treat the dimuon pair with close to the J/ψ meson invariant mass as a J/ψ candidate. We adopt the probability of 80% to register muon, and a pion misidentification of 1%. The probability density to obtain the experimental value of muon momentum p while its true value to be p_0 is expressed as $w(p, p_0) = a^{-1}e^{-(p-p_0)/a}$, where $a = \sqrt{2\pi} \cdot 0.015 \cdot p_0$. We consider the 2 sources of background events: the decays of other charmonium states produced in the hard QCD processes to J/ψ or $J/\psi + \gamma$, and minimum-bias (MB) events. Using heat maps for the distributions of J/ψ candidates from signal and background events against different kinematic variables of $\mu^{\pm}$, see Fig. 1, we obtain the kinematic cuts which effectively increase the signal-to-background ratio: $p_{T+} + p_{T-} > 1.25$ GeV, $p_+ + p_- > 2.9$ GeV, $|cos(\theta_+)|^2 + |cos(\theta_-)|^2 <= 1.81$, $|y_+| < 1.1, |y_-| < 1.1$.

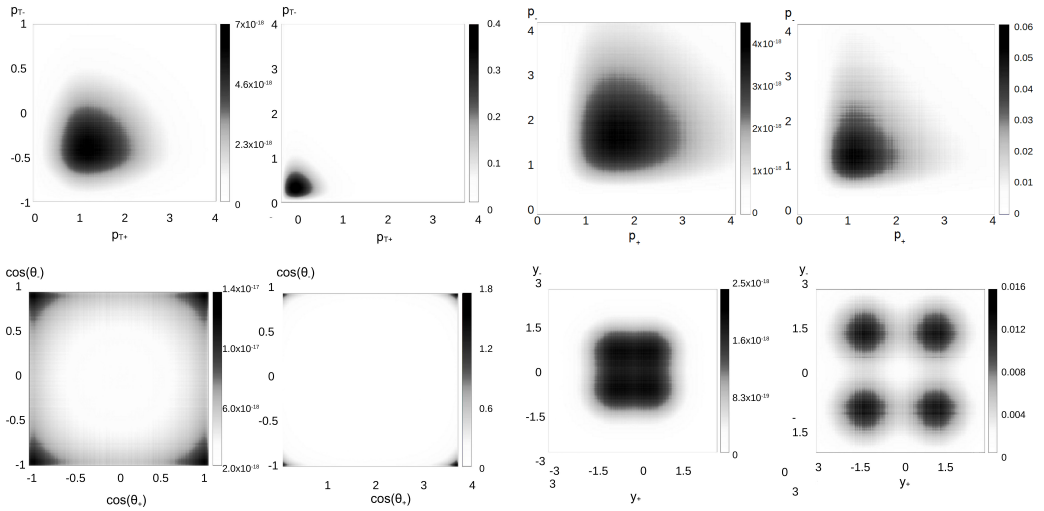

Fig. 1. J/ψ candidates distribution by p_T (left top), p (right top), $cos(\theta)$ (left bottom), rapidity y (right bottom). x (y) axis corresponds to $\mu^{+(-)}$. For each pair of distributions signal events are shown at the left, MB events at the right panel.

Applying the cuts we obtain the increase of 37.21 and 42.66 times signal-to-background ratio for NICA energies of 20 and 27 GeV, that is illustrated in the Fig. 2. The next cuts should be imposed on the associated photon, the obvious one is $p_T = 2$ GeV, together with isolation cone condition, nevertheless it would be not enough to clearly separate a signal process. So we should take a deeper look to the direct photon production and its backgrounds.

Direct photon production

The direct photon production at the energies of 19-60 GeV is dominated by Compton scattering process $g + q \to \gamma + q$. Another main process is

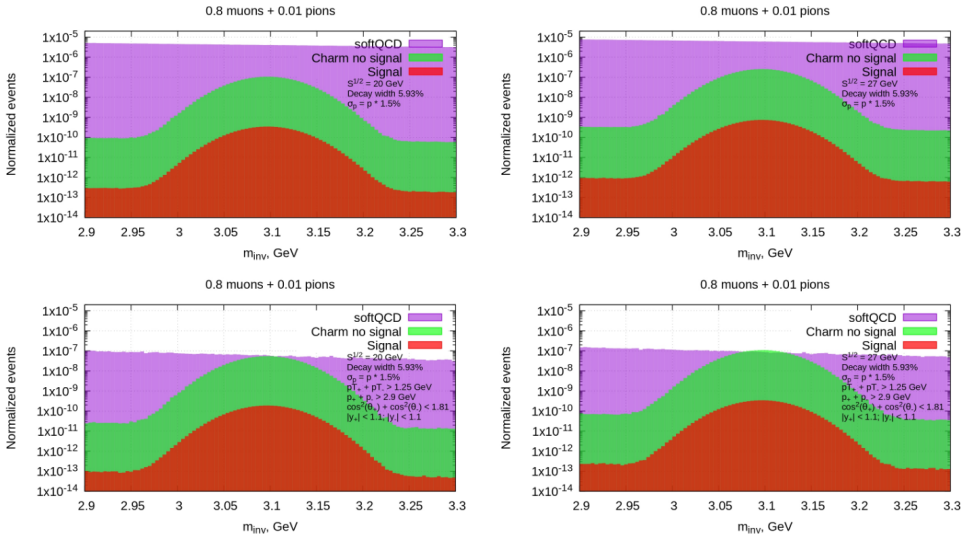

Fig. 2. The invariant mass distributions of J/ψ-mesons candidates: initial (top) and after cuts (bottom) at $\sqrt{s} = 20$ GeV (left) and $\sqrt{s} = 27$ GeV (right).

quark-antiquark annihilation $q + \bar{q} \to \gamma + g$, where $q = u, d, s$. At first, we performed PYTHIA8 [7] simulation for the experiments at the close to NICA energies of $\sqrt{s} = 27$ GeV and $\sqrt{s} = 20$ GeV to define a PYTHIA8 configuration set providing the most convenient description of experimental data. We found one switching off the non-perturbative processes such as primordial parton transverse momenta and effects of initial and final state radiation and switching on the two main hard processes of prompt photon production. The data to MC ratios for experimental data [8] at $\sqrt{s} = 19.4$ GeV and $\sqrt{s} = 22.96$ GeV in different intervals of $x_T = 2p_T/\sqrt{s}$ and x_F are presented in the Fig. 3. The background to direct photons at NICA comes from π^0 and η decays, fragmentation photons, misidentified neutral clusters and other sources [1, 2]. The main ones are the first two, where $\pi^0 \to \gamma\gamma$ dominates. Hence at first we simulated the π^0 spectra using the same PYTHIA8 configuration set, see Fig. 4, left. The data/MC ratio vary from 0.5 to 4 depending on x_F region for the π^0 transverse momentum from 4 to 6 GeV. We overestimate twice the γ/π^0 ratio parametrisation for $\sqrt{s} = 22.96$ GeV [9] in the Fig. 4, right. Finally, we simulated the direct photon (signal) and π^0 decay photon (background) spectra for the NICA energy of $\sqrt{s} = 27$ GeV. Their ratios over photon p_T and x_F are presented in the Fig. 5, left and right, respectively. At $p_T \approx 4.5$ GeV we can expect the excess of the signal events over background ones. However, this is a region of a large experimental uncertainties due to the small statistics, and the rise of η mesons decays role. Therefore, the further selection criteria are needed.

Results

We found a number of kinematic cuts for the selection of J/ψ-meson candidates in a photon-associated J/ψ-meson production in pp interactions

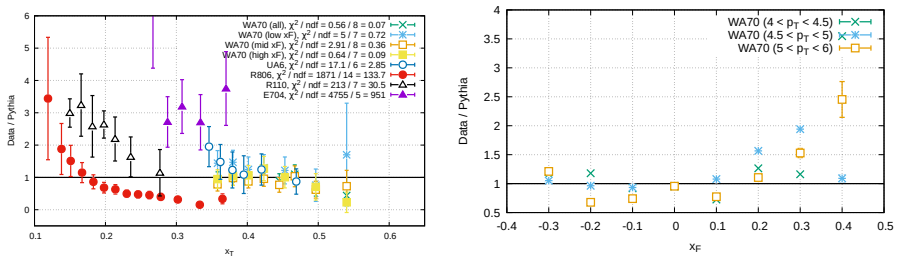

Fig. 3. Ratios (data [8]/MC) as a function of photon x_T (left) and x_F (right).

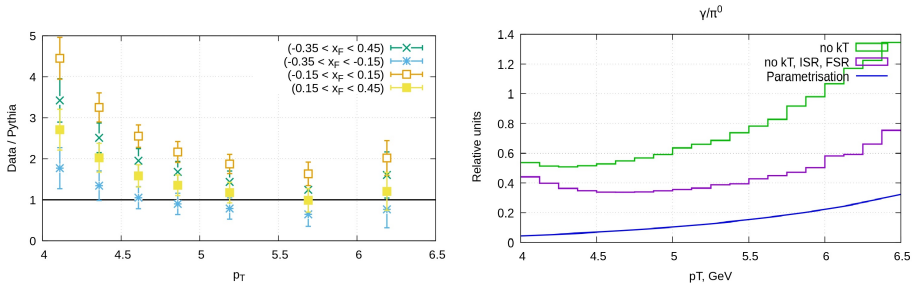

Fig. 4. Ratio (data [9]/MC) as a function of π^0 p_T (left) and γ/π^0, the parametrisation of data from [9] (right).

at SPD NICA. We used a $\mu^+\mu^-$ decay mode of J/ψ meson taking into account the sensitivity of a real detector. The proposed cuts allow to increase the ratio of the number of signal events to background ones in the signal peak region by 42.66 times at the $\sqrt{s} = 27$ GeV and 37.21 times at $\sqrt{s} = 20$ GeV. For the further study of kinematic cuts on the associated photon we studied signal and background direct photon production at the similar energies. We fixed the PYTHIA8 configuration which leads to a good description of a set of direct photon experimental data at the energies close to NICA ones. We simulated the π^0 spectra being in agreement with existing experimental data, but the higher statistics is needed for the larger p_T values. The obtained photon-to-π^0 ratio is consistent with previous measurements. We present the predictions for the signal-to-background ratio in direct photon production at NICA energies of 27 GeV in a number of p_T and x_F regions. The study of kinematic cuts on the π^0 decay photons and the following cuts on the J/ψ associated photons would be a subject of our further study.

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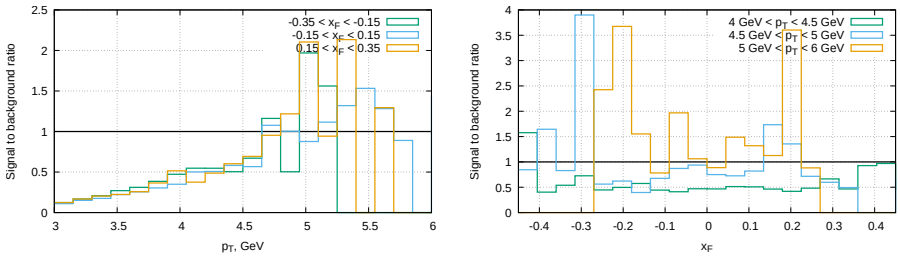

Fig. 5. Ratio (γ/π^0) against p_T (right) and x_F (left) at $\sqrt{s} = 27$ GeV.

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