Hard processes at NICA with TMD factorizations

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Measurements of the lepton pair (Drell-Yan), J/ψ and direct photon production in collisions of non-polarized, longitudinally and transversally polarized proton and deuteron beams are suggested to be performed at the collider NICA of the JINR using the specialized Spin Physics Detector (SPD).

At kinematical conditions of NICA collider ($\sqrt{S} = 24$ GeV, $1 < p_T < 6$ GeV, $Q^2 \gtrsim 1$ GeV^2) effects related with intrinsic non-perturbative transverse motion of partins inside hadrons are important and some form of Transverse-Momentum-Dependent (TMD) factorization should be used for theoretical predictions, rather than conventional LO and NLO fixed order calculations in the Collinear Parton Model (CPM). The well-known Collins-Soper-Sterman (CSS) TMD approach is mostly suitable for the situation when $Q \gg p_T \gg \Lambda_{\mathrm{QCD}}$ and it's application at low energies is spoiled by significant power corrections.

In the case of Drell-Yan pair production gauge invariance of the hadronic tensor is violated by next-to-leading power perms $O(p_T/Q)$ which are important for the case of Drell-Yan helicity structure functions $F_{UU}^{(2)}$, $F_{UU}^{\cos\phi}$ and $F_{UU}^{\cos 2\phi}$ see [*M. Nefedov, V. Saleev. Off-shell initial state effects, gauge invariance and angular distributions in the Drell-Yan process, Phys.Lett. B790 (2019) 551-556.*].

In J/ψ production: CSS TMD approach formally can be used only for $\Lambda_{\mathrm{QCD}} < p_{T\psi} \ll M_\psi$, such a way only at very low $p_T \lesssim 1$ GeV. The fixed order calculation in CPM gives reliable predictions at large $p_T > 4$ GeV only. To describe intermediate region $1 < p_T < 4$ GeV, which will be studied at SPD NICA experiment, we should use new approach, which smoothly interpolate between these two regions.

In direct photon production: because of absence of second large hard scale, like J/ψ mass or invariant mass Q of DY pair, CSS can't be used to calculate direct photon production directly.

Here we suggest to use the parton Reggeization approach (PRA) [*M.A. Nefedov, A.V. Karpishkov, V.A. Saleev. $B\bar{B}$ angular correlations at the LHC in the parton Reggeization approach merged with higher-order matrix elements, Phys. Rev. **D96** (2017) 096019.*] for modeling of hard processes

at NICA. Originally developed for hard processes at high energy, modified PRA can be used successfully for energy range of NICA collider. We demonstrate it's application for DY, prompt J/ψ and isolated photon production considering old data from RHIC, CERN SPS and FNAL.

In PRA, we preserve gauge invariance of hard off-shell amplitudes, obtain infra-red safe p_T-spectra and include major part of high-order QCD corrections using unintegrated PDFs. Currently our studies are done in the LO in α_s, but PRA can be generalized to NLO level in strong coupling constant [*M.A. Nefedov, V.A. Saleev. From LO to NLO in the parton Reggeization approach EPJ Web Conf. 191 (2018) 04007*].