Although light-front wave functions depend on the boundary condition of the gauge potential in the light-cone gauge, physical observables cannot depend on this choice because of gauge invariance [7, 10]. In particular, the single-spin asymmetry in semi-inclusive deep inelastic polarized proton deep inelastic scattering $\ell p^{\uparrow} \to \ell' q X$ and the associated quark Sivers function can be formulated simply as the overlap of augmented LFWFs using the advance boundary condition [12]. In particular, it is the phase difference between the LFWFs for the S and P-wave Fock components that contributes to the quark Sivers function in the quark-diquark model studied in Ref. [5]. The imaginary phases are calculated by using the general formalism Eq. (6) with similar expression as Eq. (8).

The result for the Sivers single-spin asymmetry using augmented LFWFs is identical to that found in Ref. [5] using conventional LFWFs (with the principal value boundary condition), together with an explicit calculation of the final state phases which arise from the rescattering of the struck quark with the spectator diquark after the lepton-quark interaction. This identity is possible since the final-state phase due to rescattering is independent of the momentum transferred in the lepton-quark interaction. On the other hand, If we choose the retarded boundary condition, the augmented wave function will have opposite imaginary part. However, under this boundary condition, we have to take into account the final state interaction effects (the gauge link contributions from the quark distributions), but again, this leads to the same result compared to that using the advanced boundary condition.

Similar conclusions hold for the small-x parton distribution calculated in [10]. We leave this topic for a future publication.

IV. SUMMARY AND DISCUSSIONS

We have use light-front time-ordered perturbation theory to obtain augmented light-front wave functions which contain an imaginary phase which depends on the choice of advanced or retarded boundary condition for the gauge potential in light-cone gauge. We have applied these results to construct augmented wavefunctions for the three-quark or quark-diquark Fock state components of nucleon and the quark-antiquark component of the pion. We obtain the leading-twist quark Sivers function from these augmented light-front wavefunctions, by applying the overlap formalism [12]. The result is identical to the explicit calculation [5] of the single spin-asymmetry in semi-inclusive deep inelastic lepton-polarized