TRANSVERSE SPIN / TRANSVERSE MOMENTUM ANALOGY AND GAUGE INVARIANCE OF DEEPLY VIRTUAL COMPTON SCATTERING

B. PIRE
CPhT[a], École Polytechnique,
F-91128 Palaiseau, France
E-mail: pire@cpht.polytechnique.fr

O. V. TERYAEV
Bogoliubov Laboratory of Theoretical Physics,JINR,
Dubna 141980, Russia
E-mail: teryaev@thsun1.jinr.ru

Using the similarity between twist 3 contributions to transverse spin for usual parton distributions and transverse momentum for non-diagonal parton distributions, we determine for the simple case of a scalar (pion, He^4) target the linear in transverse momentum twist-3 contribution to Deeply Virtual Compton amplitude. This allows to write a gauge invariant amplitude for this non-forward process.

Deeply Virtual Compton Scattering (DVCS) is a new hard process which recently attracted much attention[1,2]. It gives access to new hadronic quantities which may turn to be important for describing the physics of confinement: the non-diagonal (off-forward, skewed) parton distributions. It is known that the DVCS amplitude is not manifestly gauge invariant, the violation coming as an effect of non-zero transverse momentum Δ_T between the ingoing and outgoing protons. We show here that a fruitful analogy between transverse spin effects in usual deep inelastic scattering on the one hand and transverse momentum effects in DVCS on the other hand helps to resolve this problem.

Let us first unravel the physical nature of the problem. Gauge invariance is intimately related to the possibility of expressing the Lagrangian in terms of covariant derivatives. These derivatives mix usual momentum and the gauge field. It is thus in general impossible to separate transverse momentum effects from an additionnal gluon interaction. In terms of Operator Product Expansion, parton transverse momentum effects are at the same level as operators containing an additionnal gluon to the minimum number of quark fields. Thus only the sum of quark and quark gluon contributions is gauge invariant. The situation is well known in the case of transverse polarization for deep inelastic

[a]Unité Mixte de Recherche C7644 du Centre National de la Recherche Scientifique

scattering, *i.e. forward* virtual Compton scattering [3]. The gauge invariant result appears only when both quark and quark gluon matrix elements are taken into account. They are combining the two sources of transverse spin effects, namely, intrinsic transverse momentum and the transverse gluon field, to a gauge invariant structure, related to the covariant derivative. By making use of the equations of motion the transverse spin-dependent part of DIS hadronic tensor may be written in the manifestly gauge invariant form, depending on the single matrix element $c_T(x)$:

$$
\begin{aligned}
W^{\mu\nu} &= \frac{iM}{pq} g_T(x_B) \epsilon^{\mu\nu\alpha\beta} q^\alpha s_T^\beta, \qquad (1)\\
g_T(x) = g_1(x) + g_2(x) &= \frac{1}{2}(c_T(x) + c_T(-x)),\\
2M s_\mu c_T(x) &= \int d\lambda e^{i\lambda x} \langle p, s|\bar{\psi}(0)\gamma_\mu\gamma^5\psi(\lambda n)|p, s\rangle
\end{aligned}
$$

Let us now turn our attention to the off-diagonal case. The dependence of the matrix element $< p + \Delta/2|O|p - \Delta/2 >$ is similar to the dependence on the transverse polarization. The similarity between the forward matrix element of the polarized particle, and the non-forward matrix element comes form the fact, that in both cases one has a dependence on an extra space-like vector, orthogonal to the particle momentum (provided the latter is chosen in a symmetric way [1]). Such a procedure is valid for scalar or longitudinally polarized particles. For spin 1/2 particles, the matrix elements depend in principle of two vectors, the spin and the transverse momentum and the analogy with the forward case should be worked out with the tensor polarization of spin 1 particles. In the case of longitudinal spin, the spin vector is not independent from the momentum and we may treat the matrix element as in the scalar particle case.

There are however two important distinctions. First, the dependence on the transverse polarization is linear, like for any density matrix, while this is definitely not the case for the dependence on Δ_T. Second, the polarization is a pseudovector, contrarily to the transverse momentum. To meet with the first point we restrict ourselves to the first non-vanishing term, linear in Δ_T. The second point is a mere technicality, as now the matrix elements containing Dirac matrices γ_μ and $\gamma_\mu\gamma_5$ just interchange their kinematical structure. The extra γ_5 factor may be attributed to the one of the photon vertices, so that the *electromagnetic* contribution to the DVCS is related to parity violating term[4] in the forward case. The twist-3 contribution to the latter is known to be expressed [5] in terms of the same matrix element (c_T) as appearing in the parity conserving case (1)

$$W^{\mu\nu} = \frac{M}{pq}(c_T(x_B) - c_T(-x_B))[\tilde{p}^\mu s_T^\nu + \tilde{p}^\nu s_T^\mu], \quad \tilde{p}^\mu = p^\mu - q^\mu \frac{pq}{q^2}. \qquad (2)$$

The expression for the off-diagonal hadronic tensor keeping only linear terms in Δ_T is then explicitely gauge invariant

$$H^{\mu\nu} = \frac{M}{pq}\int_0^1 dx c_\Delta(x)(\frac{1}{x-\xi} + \frac{1}{x+\xi})[\tilde{p}^\mu \Delta_T^\nu + \tilde{p}^\nu \Delta_T^\mu], \qquad (3)$$

$$2M\Delta_T^\mu c_\Delta(x) = \int d\lambda e^{i\lambda x}\langle p + \Delta/2|\bar{\psi}(0)\gamma^\mu \psi(\lambda n)|p - \Delta/2\rangle.$$

Another proposal has been done[6] to correct the DVCS amplitude by adding a term proportionnal to Δ_T. This is different from our proposed definition as their result is governed by the same distribution H, whether Δ_T vanishes or not. At the same time, our result (3) reveals the kinematical structure of $\Delta_T = 0$ case (the appearing tensor structure is actually the linear in Δ_T part of the tensor $\tilde{p}^\mu \tilde{p}^\nu$, whose coefficient is just the standard F_2 structure function), but multiplied by the different long-distance matrix element. Here the analogy with the transverse polarization is also clear. The kinematical structure of the hadronic tensor for longitudinal and transverse polarization is the same $\epsilon^{\mu\nu\alpha\beta}q^\alpha s^\beta$, while their coefficients differ by the structure function g_2. Such a difference is manifested because of the light cone direction violating the rotational invariance, which is restored for the local operators for the first moments, resulting in the Burkhardt-Cottingham sum rule. We expect the similar sum rule to be valid in the non-diagonal case.

O.T. is indebted to A.V. Radyushkin for enlightening discussion on the difference between longitudinal and transverse momentum transfer in DVCS.

References

1. X. Ji, Phys. Rev. **D55** (1997) 7114.
2. A.V. Radyushkin, Phys. Lett. **B380** (1996) 417; Phys. Lett. **B385** (1996) 333; Phys. Rev. **D56** (1997) 5524; J.C. Collins, L. Frankfurt and M. Strikman, Phys. Rev. **D56**, 2982 (1997); M. Diehl, T. Gousset, B. Pire and J.P. Ralston, Phys. Lett. **B411**, 193 (1997).
3. A.V. Efremov and O.V. Teryaev, Yad. Fiz. **39** (1984) 1517.
4. see e.g. J. Blümlein and N. Kochelev, Nucl. Phys. **B498** (1997) 285.
5. X. Ji, Nucl. Phys. **B402** (1993) 217.
6. P.A.M. Guichon and M. Vanderhaegen, Prog. Part. Nucl. Phys. **41** (1998) 125.