IL NUOVO CIMENTO **44 C** (2021) 61
DOI 10.1393/ncc/i2021-21061-2

Communications: SIF Congress 2020

Azimuthal asymmetries in unpolarized semi-inclusive deep inelastic scattering at COMPASS

A. Moretti for the COMPASS Collaboration

Università di Trieste e INFN, Sezione di Trieste - Trieste, Italy

received 15 January 2021

Summary. — The amplitude of the modulations in the azimuthal angle distribution (azimuthal asymmetries) of hadrons produced in the semi-inclusive deep inelastic scattering on an unpolarized nucleon carries information on the intrinsic transverse momentum of the quark and on the Boer-Mulders parton distribution function. Using the data collected with a 160 GeV muon beam scattering off a liquid-hydrogen target, the COMPASS Collaboration has recently measured the azimuthal asymmetries $A_{UU}^{\cos\phi_h}$, $A_{UU}^{\cos 2\phi_h}$ and $A_{LU}^{\sin\phi_h}$ of charged hadrons. The preliminary results shown here confirm the strong kinematic dependencies observed in previous measurements.

1. – Introduction

The role of the intrinsic degrees of freedom in the description of the nucleon structure is nowadays well acknowledged. The standard collinear Quantum Chromodynamics and the parton model, successful in describing a large amount of data at high energy, cannot explain all the observed phenomena (see, *e.g.*, ref. [1]). In recent years, tremendous effort has been undertaken to formalize (on the theoretical side) and to measure (on the experimental side) the effects arising from the transverse degrees of freedom, namely the quark intrinsic transverse momentum, the quark transverse spin and the nucleon transverse spin. One of the building blocks needed for a complete description of the nucleon structure are the Transverse-Momentum–Dependent Parton Distribution Functions (TMD PDFs). They include the still unknown Boer-Mulders function $h_1^\perp$, which encodes the correlation between the quark transverse momentum and its transverse spin in an unpolarized nucleon. The Boer-Mulders PDF can be accessed in a Semi-Inclusive measurement of Deep Inelastic Scattering (SIDIS) on an unpolarized nucleon, where it couples to the Collins fragmentation function (FF) $H_1^\perp$, originating well-defined modulations in the azimuthal angle of the final-state hadron. The fully differential cross section for the production of a hadron h of transverse momentum P_T reads [2]:

$$(1)\qquad \frac{\mathrm{d}\sigma}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi_h\,\mathrm{d}P_T^2} \propto 1+\varepsilon_1 A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon_2 A_{UU}^{\cos 2\phi_h}\cos 2\phi_h+\varepsilon_3\lambda A_{LU}^{\sin\phi_h}\sin\phi_h,$$

where x is the Bjorken variable, y is the fraction of the beam energy carried by the virtual photon in the target rest frame, z is the fraction of the photon energy carried by the hadron in the target rest frame, ϕ_h is the hadron azimuthal angle in a system where the z-axis is along the virtual photon, the y-axis is perpendicular to the lepton plane and the x-axis is chosen to have a right-handed system. The ε_i terms are kinematic factors depending on y and λ is the beam polarization. At twist-3, $h_1^\perp$ enters the expression of the two azimuthal asymmetries $A_{UU}^{\cos\phi_h}$ and $A_{UU}^{\cos 2\phi_h}$:

$$A_{UU}^{\cos\phi_h} \propto \frac{2M}{Q}\mathcal{C}\left[-\frac{(\hat{h}\cdot\vec{p}_\perp)\vec{k}_T^2}{z^2M^2M_h}h_1^\perp H_1^\perp - \frac{(\hat{h}\cdot\vec{k}_T)}{M}f_1D_1 + \dots\right], \tag{2}$$

$$A_{UU}^{\cos 2\phi_h} \propto \mathcal{C}\left[-2\frac{(\hat{h}\cdot\vec{k}_T)(\hat{h}\cdot\vec{p}_\perp)-(\vec{k}_T\cdot\vec{p}_\perp)}{zMM_h}h_1^\perp H_1^\perp\right], \tag{3}$$

where $\hat{h} = \vec{P}_T/|\vec{P}_T|$, $\vec{p}_\perp$ is the transverse momentum acquired by the hadron in the fragmentation, $\vec{k}_T$ the quark intrinsic transverse momentum, M and M_h the proton and hadron masses, respectively, f_1 and D_1 are the unpolarized PDF and FF. The symbol $\mathcal{C}$ denotes the convolution over the unobservable transverse momenta $\vec{p}_\perp$ and $\vec{k}_T$. In the $A_{UU}^{\cos\phi_h}$ asymmetry, the main contribution arises from the Cahn effect [3] and this asymmetry is relevant to get information on $|\vec{k}_T|$.

Measurements of azimuthal asymmetries have been performed in the past by COMPASS [4], HERMES [5] and CLAS [6]. The COMPASS published results, from data collected in 2004 on a ^{6}LiD target with a positive muon beam, showed strong kinematic dependencies of the azimuthal asymmetries for both positive and negative hadrons. Both the evaluation of the intrinsic quark momentum $|\vec{k}_T|$ and the extraction of the Boer-Mulders TMD from published data have not been conclusive so far [7-9].

2. – Data selection and diffractive background treatment

New preliminary results have been obtained in COMPASS from $\sim 11\%$ of the data collected during the 2016 and 2017 runs with 160 GeV/c μ^+ and μ^- beams and a 2.5 m long liquid-hydrogen target. The DIS events have been selected asking for $Q^2 > 1$ (GeV/c)^2, $0.2 < y < 0.9$, mass of the hadronic final state $W > 5$ GeV/c^2 and $0.003 < x < 0.130$. The hadron tracks have been required to have $0.2 < z < 0.85$ and 0.1 GeV/c $< P_T <$ 1.0 GeV/c.

A relevant source of background in the sample of selected hadrons is constituted by the decay products of diffractive vector mesons (in particular, $\rho^0 \to \pi^+\pi^-$, $\phi \to K^+K^-$ and $\omega \to \pi^+\pi^-\pi^0$). As the target nucleon is generally kept intact, the diffractive event (and, as a consequence, the decay hadrons) can be referred to as *exclusive*. The fraction of exclusive hadrons in the reconstructed sample depends on the kinematics, being larger at large z and small x, Q^2 and P_T [10]. Moreover, it has recently been demonstrated [11] that the exclusive hadrons can show large kinematic-dependent azimuthal asymmetries. The contamination due to the decay of diffractive vector mesons and the impact on the azimuthal asymmetries have been evaluated on the 2016 data using the HEPGEN Monte Carlo [12]. While the contribution of the ω meson has been estimated negligible, ρ^0 and ϕ contributions are sizable. The Monte Carlo samples have been normalized to the experimental data by equalizing the missing energy distributions of those events in which

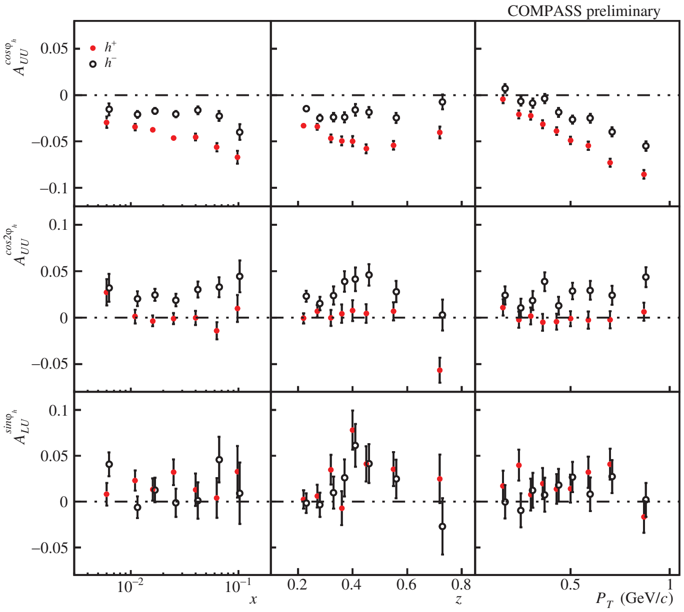

Fig. 1. – Top row: $A_{UU}^{\cos\phi_h}$ for h^+ (closed points) and h^- (open points) as a function of x (left), z (centre) and P_T (right). Middle and bottom rows: the same for $A_{UU}^{\cos 2\phi_h}$ and $A_{LU}^{\sin\phi_h}$, respectively.

both decay hadrons were reconstructed. The same events have been discarded from the data sample. The azimuthal angle distribution of exclusive hadrons, as obtained from the normalized Monte Carlo, has then been subtracted, bin by bin, from the corresponding distribution for the reconstructed hadrons. The correction for acceptance has been estimated using a Monte Carlo based on the LEPTO generator [13].

3. – Preliminary results

The azimuthal asymmetries $A_{UU}^{\cos\phi_h}$, $A_{UU}^{\cos 2\phi_h}$ and $A_{LU}^{\sin\phi_h}$ have been extracted by fitting, in each kinematic bin, the background and acceptance-corrected distribution of the hadron azimuthal angle ϕ_h. The procedure has been applied on positive and negative hadrons independently; it has been done both in bins of x, z or P_T (fig. 1) and binning simultaneously in x, z and P_T (fig. 2). In the multi-dimensional case, the z and P_T ranges have been enlarged. The results shown here have been obtained combining μ^+ and μ^- results, which are in good agreement. The dependence of the azimuthal asymmetries on the kinematic variables is strong as observed on a deuteron target in the past. The $A_{UU}^{\cos\phi_h}$ asymmetry shows a linear dependence on P_T and more complex dependencies on x and z. The difference between positive and negative hadrons hints at a flavor dependence of $|\vec{k}_T|$ or to a relevant Boer-Mulders contribution. As the Boer-Mulders contribution is also dominant in $A_{UU}^{\cos 2\phi_h}$, and since the observed asymmetry is different from zero, the $h_1^\perp$ could be extracted from these data. The uncertainties are statistical only; as for the systematic uncertainty, $\sigma_{syst} \sim 0.5\ \sigma_{stat}$ (one-dimensional case) and $\sigma_{syst} \sim 1\ \sigma_{stat}$ (multi-dimensional case).

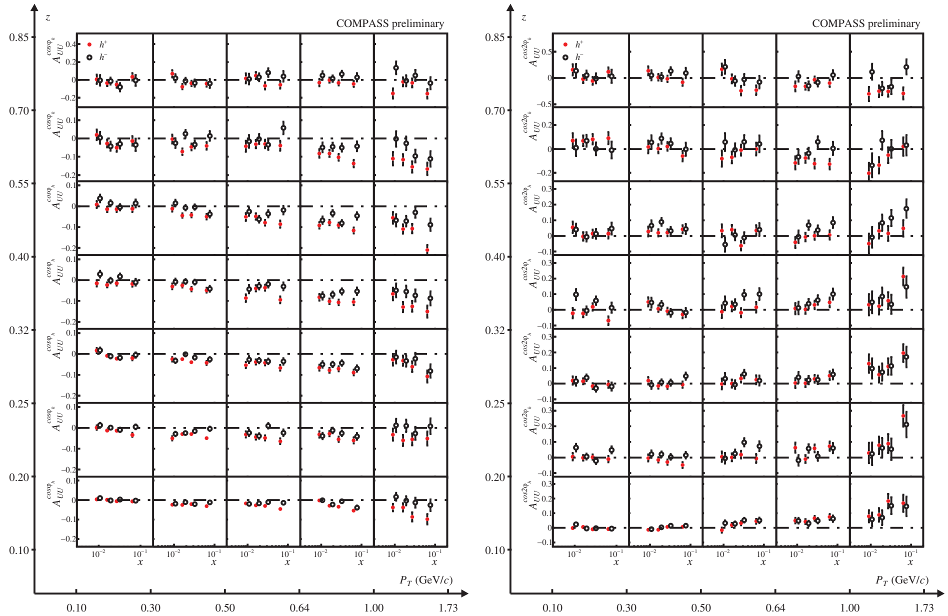

Fig. 2. – Left: $A_{UU}^{\cos\phi_h}$ asymmetry for positive (closed points) and negative hadrons (open points), as a function of x in bins of z (vertical axis) and P_T (horizontal axis). Right: the same for $A_{UU}^{\cos 2\phi_h}$.

4. – Conclusions

COMPASS has produced preliminary results for the azimuthal asymmetries of charged hadrons from part of the unpolarized SIDIS data collected in 2016. The asymmetries, extracted as a function of x, z and P_T, are strongly dependent on these kinematic variables and will be of great importance for the extraction of the Boer-Mulders function and of the intrinsic quark transverse momentum $|\vec{k}_T|$.

REFERENCES

[1] STAR Collaboration (Abelev B.I. *et al.*), *Phys. Rev. Lett.*, **101** (2008) 222001.
[2] Bacchetta A., Diehl M., Goeke K., Metz A., Mulders P. J. and Schlegel M., *JHEP*, **02** (2007) 093.
[3] Cahn R. N., *Phys. Lett. B*, **78** (1978) 269.
[4] COMPASS Collaboration (Adolph C. *et al.*), *Nucl. Phys. B*, **886** (2014) 1046.
[5] HERMES Collaboration (Airapetian A. *et al.*), *Phys. Rev. D*, **87** (2013) 012010.
[6] CLAS Collaboration (Osipenko M. *et al.*), *Phys. Rev. D*, **80** (2009) 032004.
[7] Anselmino M., Boglione M., D'Alesio U., Kotzinian A., Murgia F. and Prokudin A., *Phys. Rev. D*, **71** (2005) 074006.
[8] Barone V., Lu Z. and Ma B.-Q., *Phys. Lett. B*, **632** (2006) 277.
[9] Boglione M., Melis S. and Prokudin A., *Phys. Rev. D*, **84** (2011) 034033.
[10] COMPASS Collaboration (Aghasyan M. *et al.*), *Phys. Rev. D*, **97, 3** (2018) 032006
[11] COMPASS Collaboration (Agarwala J. *et al.*), *Nucl. Phys. B*, **956** (2020) 115039
[12] Sandacz A. and Sznajder P., arxiv:1207.0333.
[13] Ingelman G., Edin A. and Rathsman J., *Comput. Phys. Commun.*, **101** (1997) 108.