

## Fragmentation functions measurement at COMPASS

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**Summary.** — Semi-inclusive hadron muoproduction on deuterons has been measured at the COMPASS experiment at CERN using a 160 GeV muon beam. The measurement of single hadron and hadron pair multiplicities will be presented and a NLO QCD analysis of the presented data will be shown and discussed.

PACS 13.87.Fh – Fragmentation into hadrons.

PACS 13.60.-r – Photon and charged-lepton interactions with hadrons.

PACS 13.60.Hb – Total and inclusive cross sections (including deep-inelastic processes).

### 1. – Introduction

Semi-inclusive muoproduction is a crucial tool to study simultaneously the internal structure of the nucleon and the quark hadronisation mechanism. It is described by hard lepton-parton scattering cross section which can be computed in perturbative chromodynamics (pQCD) convoluted with universal non-perturbative distribution/fragmentation functions. The fragmentation functions encode all information about the hadronisation mechanism which describes the collinear transition of a parton into a hadron in the final state. It is relevant in every hard scattering reaction where hadrons are observed. Nowadays the hadronisation mechanism remains at a very preliminary stage of knowledge with a growing interest in more accurate and precise measurements of fragmentation functions. Two aspects of this process will be discussed: Single-hadron (FFs) and hadron pair (DFFs) fragmentation functions. While the FFs represent a key element in the flavor separation of polarized Parton Distribution Functions (PDFs) and play a particular role in the  $\Delta S$  puzzle, the DFFs are crucial to access the transversity, a poorly known cornerstone in the nucleon spin structure. While pion FFs are known with limited precision and kaon FFs are poorly known, the situation for DFFs turns out to be behind the schedule and nor experimental neither theoretical studies have been performed yet. In the present analysis we are interested in the current fragmentation which is the hadronisation of the struck quark and we will not study the target fragmentation produced by the spectator quark. Semi-inclusive  $\gamma N \rightarrow hX$  allows flavor and charge separation, disentangles between quark and antiquark hadronisation.

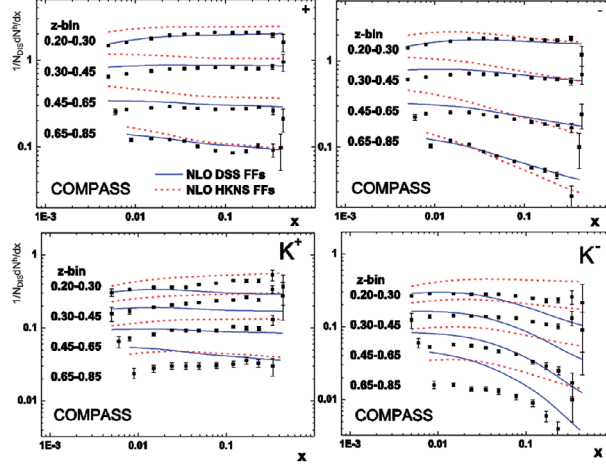


Fig. 1. – Charged pion (upper row) and kaon (lower row) COMPASS multiplicities *vs.*  $x$  and  $z$  compared to NLO QCD calculations performed by E. Leader, A. Sidorov and D. Stamenov using MSTW PDFs and DSS (blue curves) and HKNS (red dotted curves) fragmentation functions.

The semi-inclusive  $\gamma(q)N(P) \rightarrow h(p_h)X$  reaction, where  $q$ ,  $P$  and  $p_h$  denote the four-momenta of the virtual photon  $\gamma$ , the nucleon  $N$  and the observed hadron  $h$  while  $X$  denotes unobserved hadrons, is described by the virtual photon transfer four-momentum squared  $Q^2 = -q^2$ , the Bjorken variable  $x = -q^2/(2P \cdot q)$ , the lepton energy fraction carried by the virtual photon  $y$ , the invariant mass of the final hadronic system  $W = \sqrt{(P + q)^2}$  and the virtual photon energy fraction carried by final-state hadron  $z = (P \cdot p_h)/(P \cdot q)$ . The most relevant observable to measure in SIDIS to study the hadronisation mechanism is the hadron multiplicity defined in eq. (1) for the single-hadron case. It depends simultaneously upon the PDFs ( $q(x, Q^2)$ ) and the FFs ( $D_q^h(z, Q^2)$ ).

$$(1) \quad M^h(x, Q^2, z) = \frac{d^3\sigma^h(x, Q^2, z)/dx dQ^2 dz}{d^2\sigma^{DIS}(x, Q^2)/dx dQ^2} = \frac{\sum_q e_q^2 q(x, Q^2) \cdot D_q^h(z, Q^2)}{\sum_q e_q^2 q(x, Q^2)}.$$

Experimentally, a hadron multiplicity defines the averaged number of hadrons produced per DIS event, normalized by the acceptance correction factor which takes into account the limited angular and geometrical acceptance covered by the experimental apparatus as well as the kinematic smearing.

## 2. – Single-hadron multiplicities: data analysis & results

The data were collected at the COMPASS experiment at CERN using a 160 GeV/ $c$  muon beam and a deuteron target ( ${}^6\text{LiD}$ ) during the 2004 data taking. COMPASS offers the particle identification ability with the RICH detector which restricts the momentum coverage to  $[3/10, 50]$  GeV/ $c$  for  $\pi/K$ . The measurement was performed in the kinematic domain  $Q^2 > 1$  (GeV/ $c$ ) $^2$ ,  $0.1 < y < 0.9$  and  $0.004 < x < 0.7$ . To avoid kinematic regions with large and non-uniform acceptance,  $W$  is required to be greater than 7 GeV/ $c$ . Hadrons produced in the target fragmentation region and exclusive reactions are rejected by requiring  $z$  to lie in the range  $[0.2, 0.85]$  respectively.

Figure 1 shows charged pion and kaon multiplicities *vs.*  $x$  and  $z$  in comparison with NLO QCD predictions calculated using MSTW PDFs and DSS/HKNS fragmentation functions. Pion results show a reasonable agreement with NLO predictions except for

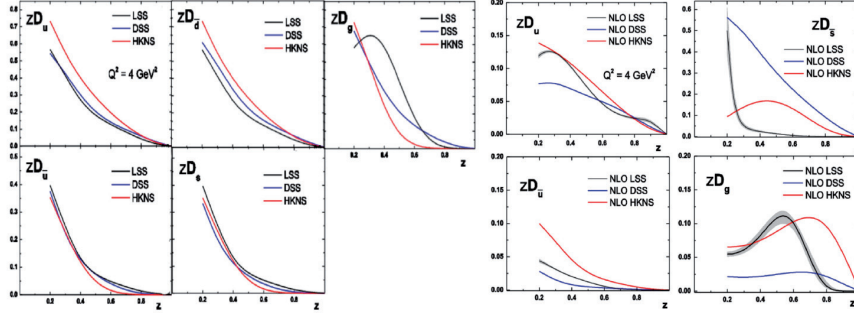


Fig. 2. – Pion (a) and kaon (b) FFs extracted from COMPASS charged hadron multiplicities (denoted LSS) in comparison with DSS (blue) and HKNS (red) FFs at  $Q^2 = 4$  (GeV/c) $^2$ .

$x < 10^{-2}$  and  $z > 0.65$ . For kaons, significant discrepancies are observed in the full  $z$  range highlighting that COMPASS data favor different FFs than existing sets. The  $Q^2$  dependence of the hadron multiplicities is also studied with a fine binning in  $z$  and found to be non-negligible for both pions and kaons. Systematic uncertainties were estimated and found to be  $\sim 5(10)\%$  for  $\pi(K)$ , where the largest contribution is due to particle identification (more details can be found in [1]). In order to reduce the systematic errors, the data collected in 2006 on deuteron target with a different apparatus is being analyzed. The final goal is to provide COMPASS multiplicities to world-data global QCD analyzers.

### 3. – Single-hadron fragmentation functions

A recent NLO QCD fit of fragmentation functions to these COMPASS multiplicities was performed by E. Leader *et al.* [2]. The main goals of this work is to estimate the level of agreement between COMPASS data and the current FFs sets and to check the sensitivity of these data to the strange quark FF into kaon which is a key element in the strange quark polarization puzzle. Due to the limited number of free parameters that can be extracted from data, some relations upon the individual FFs are imposed. For pions we impose charge conjugation,  $SU2$  symmetry *i.e.*  $D_d^{\pi^+} = D_u^{\pi^+}$ ,  $D_d^{\pi^+} = D_u^{\pi^+}$  and we assume equal unfavored fragmentation functions *i.e.*  $D_d^{\pi^+} = D_u^{\pi^+} = D_s^{\pi^+} = D_s^{\pi^+}$ . This leads to three pion FFs extracted using the functional form, at the initial scale  $Q_0^2 = 1$  (GeV/c) $^2$ ,  $zD_q^{\pi} = N_q z^{\alpha_q} (1-z)^{\beta_q} (1+\gamma_q(1-z)^{\delta_q})$  for favored and unfavored FFs and  $zD_q^{\pi} = N_q z^{\alpha_q} (1-z)^{\beta_q}$  for gluon FF. For kaons, assuming charge conjugation and equal unfavored FFs, four functions were extracted using the functional forms  $zD_q^{\pi} = N_q z^{\alpha_q} (1-z)^{\beta_q} (1+\gamma_q(1-z)^{\delta_q})$  for the two favored ( $D_u^{K^+}$ ,  $D_s^{K^+}$ ) FFs and  $zD_q^{\pi} = N_q z^{\alpha_q} (1-z)^{\beta_q}$  for the unfavored and the gluon FFs.

Resulting fragmentation functions are shown in fig. 2 and compared to DSS and HKNS FFs. For pions, the fitted functions are compatible with both FF sets except for the gluon contribution where COMPASS data favor higher gluon FF. For kaons, the fitted FFs significantly disagree with existing sets especially for strange quark and gluon FFs.

### 4. – Hadron pair multiplicities: data analysis & results

The transversity function remains a poorly known element in the nucleon spin structure and is mainly addressed by the collins effect in SIDIS transverse spin asymmetries. An alternative and complementary approach is based on a spin asymmetry in

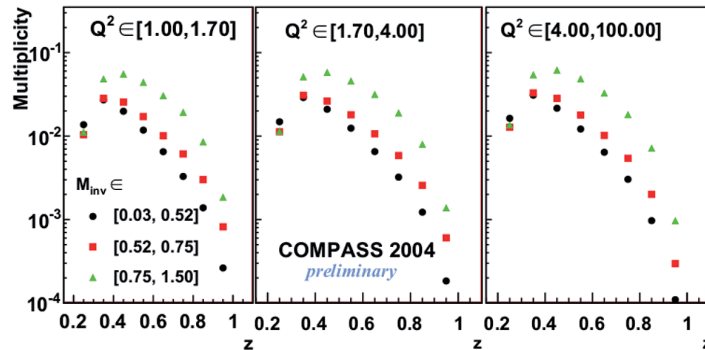


Fig. 3. – Hadron pair multiplicities *vs.*  $z$ ,  $Q^2$  and  $M_{inv}$  using COMPASS 2004 data.

the semi-inclusive  $lN^\dagger \rightarrow l'(h_1 h_2)X$  process where two unpolarized final-state hadrons emerge from the hadronisation of the struck quark. The kinematic remains similar to single-hadron case except for hadronic variables, where a hadron pair carries a fractional energy  $z = z_1 + z_2$ , with a total momentum  $P = P_1 + P_2$  and an invariant mass  $M_{inv}^2$  which naturally represents a second scale for the fragmentation. In this case, the transverse asymmetry is expressed in terms of polarized DFFs ( $H_{1,q}^{<h_1 h_2}(z, M_{inv}, Q^2)$ ) which represents the interference between the fragmentation amplitudes into hadron pairs in relative s and p waves, and in terms of unpolarized DFFs ( $D_q^{h_1 h_2}(z, M_{inv}, Q^2)$ ). While the polarized DFFs were recently measured at the BELLE experiment, the unpolarized DFFs are not yet measured. For this goal, we present the first measurement of hadron pair multiplicities in SIDIS at COMPASS using 2004 data collected on a deuteron target. The same kinematic is covered in this measurement except for the energy of the hadronic system,  $W > 5 \text{ GeV}/c$  in this case. In addition, each hadron is required to have its fractional energy larger than 0.1 and its Feynman variable larger than 0.1 to avoid the target fragmentation region. The resulting hadron pair multiplicities are shown in fig. 3 *vs.* the fractional energy of the pair  $z$ , the invariant mass of the pair ( $M_{inv}$ ) and  $Q^2$ . While the  $Q^2$  dependence is found to be negligible up to  $z = 0.8$ , a strongest dependence on  $z$  and  $M_{inv}$  is observed. No theoretical predictions exist yet for comparison. Systematic errors are estimated to 7%.

## 5. – Conclusions

Single-hadron and hadron-pair multiplicities have been measured using data collected at the COMPASS experiment at CERN by deeply inelastic muon scattering on deuterons in the kinematic domain  $Q^2 > 1 \text{ (GeV}/c)^2$ ,  $0.1 < y < 0.9$ . Single-hadron multiplicities favor different kaon FFs than existing ones and in general highlight an important contribution of the gluon FF. The first experimental measurement of hadron pair multiplicities is presented in the purpose of extracting DFFs and the transversity function. Single-hadron multiplicities are being extracted from 2006 COMPASS data and the same measurement will be done using muon-proton data taken recently by COMPASS in 2012.

## REFERENCES

- [1] MAKKE N., *Polarization of strange quarks in the nucleon and determination of quark fragmentation functions into hadrons*, PhD thesis, ParisXI University, 2011.
- [2] SIDOROV A., LEADER E. and STAMENOV D., in *SPIN12 conference*.