# Pion and Kaon Multiplicities from muon-deuteron Deep Inelastic Scattering at COMPASS

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**DOI:** `http://indico.cern.ch/contributionDisplay.py?contribId=100&confId=153252`

The hadronization process, which turns partons into non-perturbative hadronic bound states in hard-scattering reactions, plays a fundamental role in our understanding of the proton structure. Currently, our knowledge of quark Fragmentation Functions into hadrons (FFs) originates mainly from existing global QCD analyzes which are mostly based on inclusive measurements in electron-positron annihilation process. While the latter, with current available data, mainly fixes the flavor singlet combinations of FFs, semi-inclusive DIS measurements give access to the flavor structure of FFs via hadron multiplicities. The COMPASS collaboration has recently measured charge separated pion and kaon multiplicities using 160 GeV/c muons off deuteron target. This measurement makes a fundamental experimental contribution towards a deeper understanding of the hadronization process.

## 1 Introduction

Within the framework of leading-twist collinear QCD, processes with observed final-state hadrons can be described in terms of perturbative hard scattering cross sections and non-perturbative universal functions: parton distributions and fragmentation functions. While parton distributions, which describe the quark structure of initial-state hadrons, are nowadays precisely known except for strange quark distribution which still carries a large uncertainty, fragmentation functions which encode details of the hadronization process are poorly known. Current parametrizations for fragmentation functions are mainly based on single-inclusive measurements in $e^+e^-$ annihilation (see quark fragmentation chapter in [3]). While current available $e^+e^-$ data are very precise, they do not allow to disentangle quark from anti-quark fragmentation and allow only flavor singlet combinations of fragmentation functions [1]. Semi-inclusive lepton-nucleon scattering data have the advantage of disentangling the charge and the flavor structure of fragmentation functions by weighting differently contributions of quark flavors in the subsequent hadronization process. A direct access to the FFs is provided in semi-inclusive DIS via the hadron multiplicities (Eq.1), defined, in the QCD improved quark-parton model, by the averaged number of final-state hadrons produced per deep inelastic scattering event.

$$\frac{1}{\sigma^{DIS}}\frac{d\sigma^h}{dxdQ^2dz} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)} \tag{1}$$

Here the sum runs over active quark flavors. $q(x,Q^2)$ denotes Parton Distribution Function (PDF) of flavor $q$ and $D_q^h(z,Q^2)$ denotes fragmentation function of a quark of flavor $q$ into a final-state hadron of type $h$. $D_q^h$ is defined as the mean number of hadrons of type $h$ produced from the fragmentation of $q$ with fractional energies $z$ $(= E_h/E_\gamma)$ in the range $[z, z + dz]$.

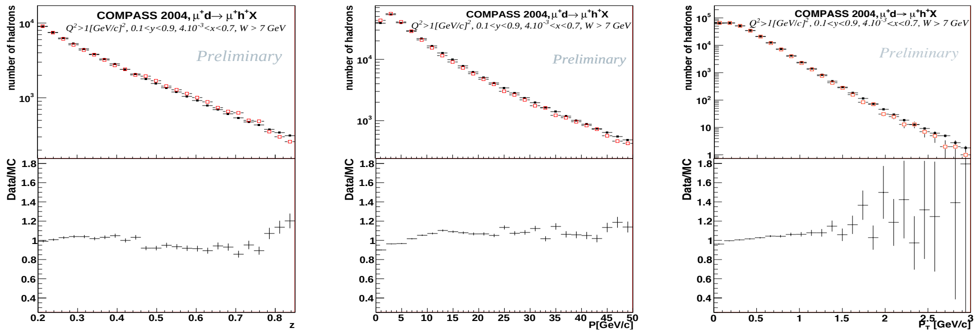
## 2 The COMPASS Experiment

COMPASS is a fixed target experiment [2] located at CERN. It uses a high energy hadron or muon beam provided by the CERN Super Proton Synchrotron (SPS). The muon beam originates from the decay of positive pions which in turn come from the scattering of a primary proton beam on a Beryllium target. The COMPASS spectrometer is 50 m long and consists of two stages designed to detect hadrons produced at small and large angles. Each stage is equipped with a magnet and a set of tracking detectors of different types. COMPASS provides particle identification through the use of a RICH detector, which is crucial for this analysis.

## 3 Experimental Data Analysis

Pion and Kaon multiplicities have been extracted using data recorded by the COMPASS experiment by scattering a 160 GeV/c polarized $\mu^+$ beam off a two cell polarized deuteron ($^6$LiD) target. The raw hadron multiplicities are first extracted from experimental data by averaging over the two target polarizations and then corrected for the acceptance of the spectrometer. This factor correction takes into account the limited geometrical and angular acceptance of the experimental apparatus, the detection inefficiency as well as the kinematic smearing. The acceptance correction factors have been estimated with a Monte Carlo (MC) simulation of $\mu$–N scattering at the COMPASS kinematics. The LEPTO generator has been used with parton shower simulation and MSTW08 parametrization for parton distributions. The COMPASS apparatus was simulated using Geant3 toolkits and finally, the hadronization process has been simulated using the Lund string model in which the intrinsic $k_T$ of quarks inside the nucleon and the hadronization parameters were tuned for a best description of COMPASS data. The Monte Carlo data are reconstruted with the same software as the experimental data. A good description of data by the produced MC sample is observed for inclusive and semi-inclusive DIS events (Fig.1).

The measurement covers a wide kinematic domain defined by cuts on the photon virtuality $Q^2 > 1$ [GeV/c]$^2$ and on the energy fraction of the lepton carried by the exchanged virtual photon $y$ $(= E_\gamma/E_\mu)$. The latter is restricted to the range [0.1, 0.9] to suppress DIS events with small energy transfer and to avoid the region the most affected by radiative effects. A cut on the invariant mass of the hadronic system $W > 7$ GeV is applied to avoid kinematic regions where acceptance corrections are smaller than 5%, in particular for the kaon case. The selected DIS event sample covers a wide range of the Bjorken variable $x \in [4.10^{-3}, 0.7]$. Produced final-state hadrons are required to have a fractional energy $z$ in the range [0.2, 0.85]. The lower cut selects only hadrons produced in the current fragmentation region (to avoid the fragmentation of the target remnant) and the upper one suppresses hadrons produced from diffractive processes. The hadron identification is ensured in the momentum range [3 (10), 50 GeV] for pions (kaons). For $P > 50$ GeV/c, the separation between pions and kaons becomes problematic. A total sample of $5.10^6$ DIS events is selected, with $10^6$ $(9.10^5)$ $\pi^+$ $(\pi^-)$ and $2.10^5$ $(1.3.10^5)$ K$^+$ (K$^-$). The analysis [3] has been performed in different combinations of bins in $x$, $z$ and $Q^2$. The radiative corrections were estimated and found to be of the order of 15% in the region $x < 0.01$ and negligible for the remaining $x$ domain. The acceptance was estimated to be $\sim 60\%$ in the covered kinematic domain, with a statistical precision of $3 - 5\%$.




(a) fractional energy $z$ (b) Hadron Momentum $P$ (c) Transverse momentun $P_T$

Figure 1: Kinematical distributions for experimental data (black markers) and simulated Monte Carlo sample (red markers) (Upper row) as well as the ratio of data to Monte Carlo (lower row).

# 4 Results

Pion and kaon multiplicities versus ($x$,$z$) are shown in Fig.2 in comparison with LO theoretical calculations performed using Eq.1, MRST04 and DSS LO parametrizations for PDFs and fragmentation functions respectively. A good agreement is observed for pions in the entire range except for $z > 0.65$. However this observation is not surprising since DSS includes semi-inclusive DIS data only up to $z = 0.65$. In the kaon case, significant discrepancies are observed in nearly the entire kinematic domain, indicating that COMPASS kaon multiplicities may have an important impact on QCD global fits of fragmentation functions and even on the determination of the unpolarized strange quark distribution function.

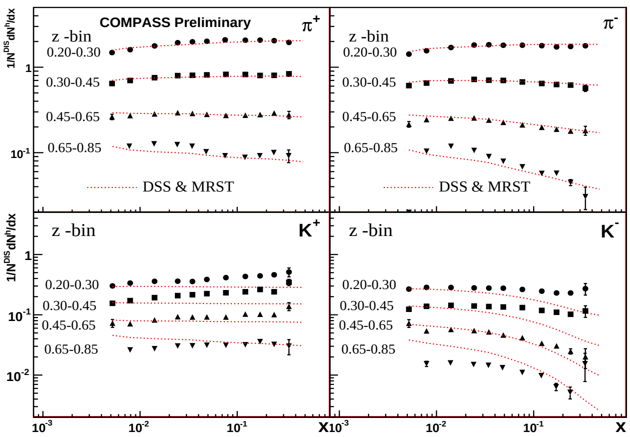
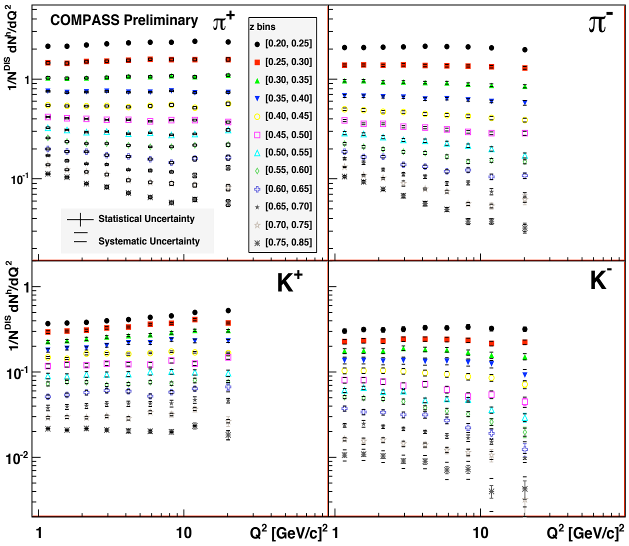
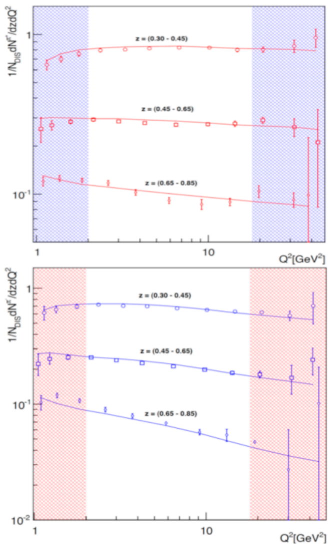



Figure 2: Charged pion (top) and kaon (bottom) multiplicities versus $x$ in four $z$ bins. Only statistical errors are shown, systematic uncertainties reache 5% for pions and 10 % for kaons.

Fig.3(a) shows pion and kaon multiplicities versus ($Q^2$,$z$). COMPASS data have the advantage of covering wide $z$ and $Q^2$ ranges. The $Q^2$ dependence is found to be more pronounced for negative hadrons than for positive ones for $z > 0.4$. This dependence originates mainly from the $x$-dependence of the PDFs and is in agreement with LO predictions. Fig.3(b) shows a first preliminary NLO fit of COMPASS pion multiplicities performed by de Florian et al. and shown in [4]. Results for kaons are also presented in [4]. While the NLO fit works well for pions, some issues have been encountered for kaons and are currently under investigations.




(a) COMPASS multiplicities versus $Q^2$




(b) A preliminary NLO fit to COMPASS pion multiplicities.

Figure 3: (a) Charged pion (top) and kaon (bottom) multiplicities as a function of $z$ in nine $Q^2$ bins. Statistical and systematic errors are shown. (b)Preliminary NLO fit of $\pi^+$ (top) and $\pi^-$ (bottom) multiplicities. Data points in the dashed region have not been included into the fit.

In conclusion, pion and kaon multiplicities have been measured by the COMPASS collaboration, using deep inelastic scattering of muons off deuteron target, in the kinematic domain $Q^2 > 1$ (GeV/c)$^2$, $0.1 < y < 0.9$, $4.10^{-4} < x < 0.7$ and $W > 7$ (GeV/c). These data have been used for a LO extraction of quark fragmentation functions [3] and are highly required for NLO global QCD analysis of fragmentation functions [4]. In the near future, the COMPASS collaboration will perform the same measurement using proton target in order to better constrain the strange quark distribution in the nucleon. The corresponding data set will be collected during this year of COMPASS data taking.

# References


[1] D. de Florian *et al.* Phys. Rev. D75 (2007) 114010; Phys. Rev. D76 (2007) 074033

[2] COMPASS Collaboration, The Compass Experiment at CERN Nucl. Intrum. Meth. A577 (2007) 455–518

[3] N. Makke, "Measurement of polarisation of strange quark in the nucleon and determination of quark fragmentation functions", *Ph.D. thesis, Paris Sud University and CEA centre de Saclay*, Orsay, France, 2011.

[4] W. Vogelsang, "QCD SPIN Physics: Some Recent Highlights", in *International Workshop on Hadron Structure and Spectroscopy, Lisbon, Portugal, 2012.*