Single hadron multiplicities in SIDIS @ COMPASS

Yann BEDFER[1], on behalf on the COMPASS Collaboration

[1] *Irfu/DPhN, CEA-Saclay, 91191 Gif/Yvette, France*

E-mail: yann.bedfer@cern.ch

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Single hadron multiplicities in SIDIS provide an important input for the understanding of the hadronisation process and its description in terms of Fragmentation Functions (FFs). The COMPASS collaboration at CERN has undertaken a programme of measurements of these observables in Semi-Inclusive DIS. In this article, I first give an overview of the results obtained so far. And I then focus on the measurement of the K-/K+ multiplicity ratio at large value of the energy fraction carried by the kaons, which results challenge the conventional picture of a factorisation between FFs and PDFs.

KEYWORDS: parton, hadron, fragmentation, pQCD.

1. Introduction

Quark and gluon fragmentation into hadrons is a core ingredient of a QCD-based analysis of hard scattering. The fragmentation process is universal, *i.e.* the hadronisation of a parton is independent of how it was produced. In the perturbative theory, it is described by non-perturbative objects called fragmentation functions (FFs). Their Q^2 evolution is described by DGLAP equations [1]. In leading order (LO) pQCD, the FF $D_i^h(z, Q^2)$ represents a probability density describing the collinear transition of parton i into a hadron h carrying energy fraction $z = E_h/E_i$. The cleanest way to access FFs is e^+e^- annihilation, $e^+e^- \to hX$. However it is only sensitive to $D_{q+\bar{q}}$ and little sensitive to flavour. Semi-inclusive DIS (SIDIS), $lN \to lhX$, is a complementary approach, sensitive to charge and flavour, but depending upon the PDFs in the nucleon N. The relevant observable is the hadron multiplicity:

$$\frac{\mathrm{d}M^h(x, z, Q^2)}{\mathrm{d}z} = \frac{\mathrm{d}^3\sigma^h(x, z, Q^2)/\mathrm{d}x\mathrm{d}z\mathrm{d}Q^2}{\mathrm{d}^2\sigma^{DIS}/\mathrm{d}x\mathrm{d}Q^2}$$

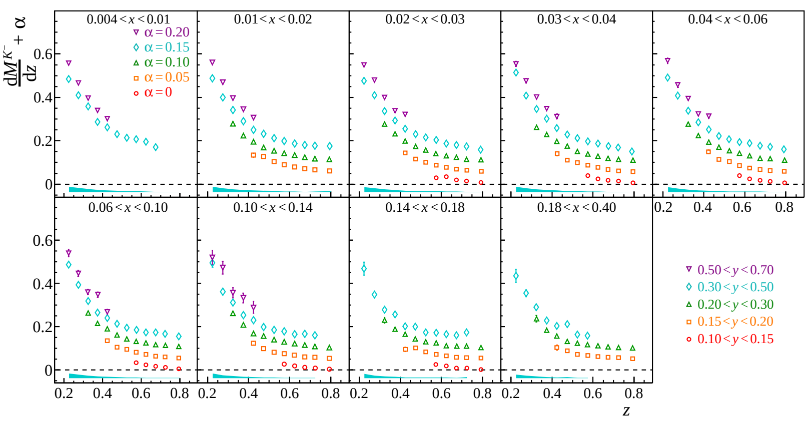

Fig. 1. COMPASS Multiplicities for K^- [3] shown *vs.* z for 9 x ranges and 5 y ranges (for better visibility staggered by a constant α). The bands correspond to the total systematic uncertainty for the range $0.30 < y < 0.50$.

2. $\pi^{\pm}$ and $K^{\pm}$ Multiplicities

The COMPASS collaboration at CERN has undertaken a programme of measurements of these multiplicity observables in $\mu N \to \mu h X$ reactions, where a hadron h is observed in the final state. Its spectrometer is designed to reconstruct scattered muons and charged hadrons in a wide kinematic range. It is equipped with a RICH for particle identification. It fulfils hence all the requirements. Results have been published for $\pi^{\pm}$ [2] and $K^{\pm}$ [3] on an isoscalar target. The corresponding data were obtained with a 160 GeV $\mu+$ beam impinging on a ^{6}LiD target. They are corrected for instrumental and radiative effects and, based on event generator HEPGEN [4], for the contamination by the decay of diffractively produced vector mesons. As an illustration, K^{-} multiplicities are shown in Fig. 1.

The extraction of the FFs is best performed by QCD fits taking into account a large number of hadron production datasets. For example, DEHSS [5, 6] consider $e^{+}e^{-}$ and pp data in addition to SIDIS. SIDIS, in particular from COMPASS and HERMES [7], plays there a crucial role in the flavour and charge separation.

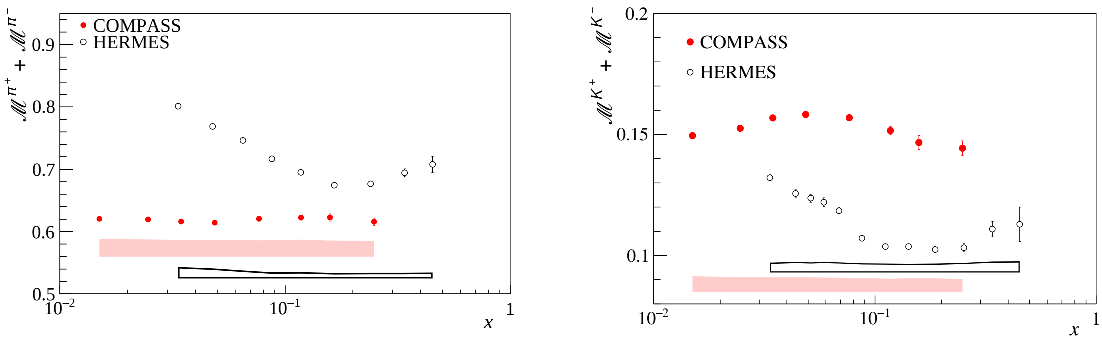

Fig. 2. Comparison of z-integrated multiplicities $\mathcal{M}$ in COMPASS [2, 3] *vs.* HERMES [7]. The $\mathcal{M}^{+} + \mathcal{M}^{-}$ sum is shown for $\pi^{\pm}$ (*left*) and $K^{\pm}$ (*right*). For $K^{\pm}$, the ratio $\mathcal{M}^{+}/\mathcal{M}^{-}$, not shown, also exhibits discrepancy.

In [2, 3], we compare our results with those from other DIS experiments, *viz.* HERMES [7], EMC [8] and JLab2 [9]. While reasonable agreement is obtained with the latter two, discrepancies are observed with respect to HERMES, see Fig. 2. The comparison is done in terms of multiplicities integrated over the measured z range, $\mathcal{M}$. Which has the advantage of minimising the sensitivity to the Q^2 scale, which differs in the two experiments. Several approaches have been pursued to handle these discrepancies. In DEHSS, they are absorbed in uncertainties arising in part from the normalisations of the datasets and otherwise, from the input PDFs. This latter observation underlines the sensitivity of the analysis of SIDIS data to the PDFs. The best way to deal with the fact is to take advantage of it to simultaneously fit FFs and PDFs. Two groups of global fits have started to implement the idea, *viz.* the above-mentioned DEHSS [10] and the JAM group [11]. In [12], the authors explore the impact of target and hadron mass corrections. These are all the more pronounced as the mass of the produced hadron is large and decrease with Q^2. The conclusion is that mass effects partially account for the discrepancy observed on the kaons, and that other corrections, possibly from higher twist effects, as well as from unquantified systematic uncertainties are otherwise at play.

3. K^{-}/K^{+} multiplicity ratio at high z

The pQCD framework whereby SIDIS cross-section factorises into a hard scattering, PDFs and FFs is only valid in the kinematical region of the current fragmentation [13]. This is usually taken into account by restricting the z range, typically $z >$ .2. COMPASS explored other limitations to this validity domain by investigating fragmentation in the high z region. For this, we determined the kaon multiplicity ratio:

$$R_K(x, Q^2, z) = \frac{\mathrm{d}M^{K^-}(x, z, Q^2)/\mathrm{d}z}{\mathrm{d}M^{K^+}(x, z, Q^2)/\mathrm{d}z}$$

In this kind of ratio, systematics connected to the instrumental apparatus and to radiative corrections cancel out, which allows to carry out this otherwise experimentally difficult investigation of the high z region. In addition, the contamination by decay products of diffractive vector mesons, which dominates at high z in the pion case, $\rho^o \rightarrow \pi^+\pi^-$, stays within 0.3< z <0.7 in the kaon case, $\phi \rightarrow K^+K^-$, because of the small break-up momentum of the ϕ meson.

The results, published in [14], are shown for one x-bin in Fig. 3, together with expectations from pQCD calculations based on the DEHSS set of FFs and from the LEPTO Monte Carlo generator [15]. To serve as a guidance, we also show a lower limit obtained using LO pQCD, isospin symmetry and reasonable assumptions on the PDFs, *viz.* $R_K > \bar{u}/u$, and a lower NLO limit obtained by setting $D_{\bar{s}}^{K+} = D_s^{K^-} = 0$. It is observed that with increasing z, the values of R_K are increasingly disagreeing with calculations and even with LO and NLO lower limits. The discrepancy between the COMPASS results and the NLO predictions reaches a factor of about 2.5 at the largest value of z. As the difference between the LO and NLO calculations is never larger than 20%, it is very unlikely that any prediction obtained at NNLO would be able to account for such a large discrepancy. Higher-twist effects cannot account either, since they are proportional to $1/Q^2$, and therefore should be smaller by a factor of about three in the second x-bin that we consider in our publication, whereas the discrepancy is found to be the same in the two x-bins within experimental uncertainties. It is worth mentioning that the factorisation approach used for string hadronisation in the LEPTO generator, in spite of its considerably higher flexibility in comparison to the independent fragmentation approach of pQCD, appears also incapable to describe the data at high z.

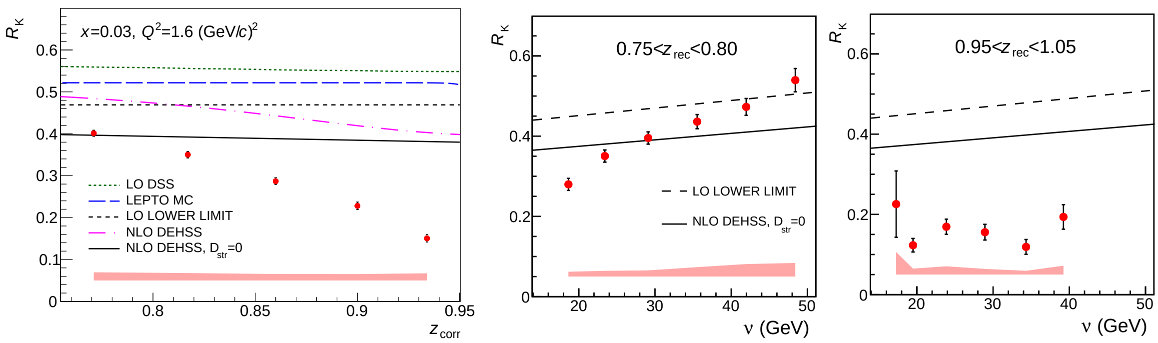

Fig. 3. *Left*: R_K (*i.e.* K^-/K^+ multiplicity ratio) as a function of z_{corr} ($\simeq z$) compared to predictions, as well as to the expected lower limit of LO pQCD. *Centre and right*: R_K as a function of the energy of the virtual-photon, ν, in two bins of z_{rec} ($\simeq z$). Statistical uncertainties are shown by error bars, systematic uncertainties by bands at the bottom.

R_K exhibits a strong dependence on the virtual-photon energy ν, except at the highest z. This is illustrated on the centre and right panels of Fig. 3. Note that at most 15% of the observed variation of R_K with ν can be explained by the fact that in a given z-bin events at different ν have somewhat different values of x and Q^2. The observed trends suggest that at even lower values of ν, like those accessible at fixed target experiments other than COMPASS, a larger range of z becomes problematic.

One possible explanation of the phenomenon we observe is that when a high z kaon is produced, little phase-space is left to the target remnants for the conservation of baryon and strangeness numbers. The relevant variable to study this aspect is the missing mass, which is approximately given by

$M_X^2 = M_p^2 + 2M_p\nu(1-z) - Q^2(1-z)^2$. Fig. 4 shows that R_K as a function of M_X follows a remarkably smooth behaviour. M_X, which dominant term is $\propto \sqrt{\nu(1-z)}$, thus simultaneously expresses both to the z and ν dependences described *supra*.

Our conclusion is that within the pQCD formalism an additional correction may be required, which takes into account the phase space available for hadronisation.

Besides, we stress that care should be applied when analysing SIDIS multiplicity data obtained at low energy.

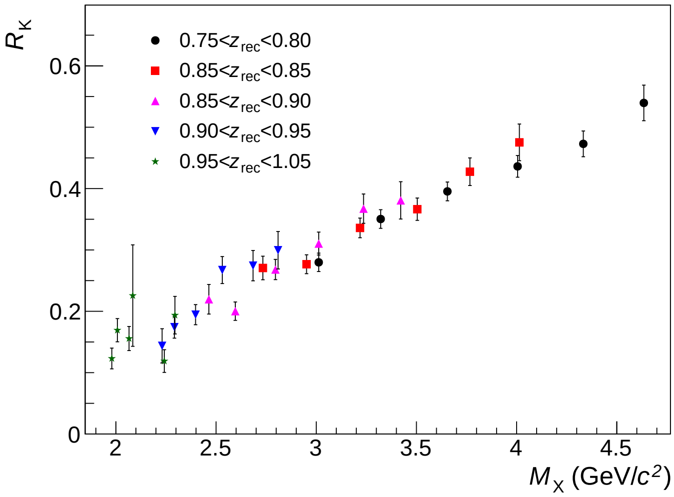

Fig. 4. K^- over K^+ multiplicity ratio R_K presented as a function of the missing mass M_X.

4. Outlook

COMPASS has collected SIDIS data on a liquid hydrogen target in 2016 and 2017. Multiplicities extracted from these data will provide interesting information on the FFs, complementary to that obtained on an isoscalar target, presented in these proceedings.

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