The fragmentation process at HERMES

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Abstract. In semi-inclusive deep-inelastic scattering one can study the fragmentation process of partons by extracting multiplicity distributions for the resulting hadrons. At the HERMES experiment a unique possibility exists to study this hadronization at a $\sqrt{s}$ of 7.2 GeV. Making full use of the hadron identification capabilities of a Ring Imaging Čerenkov (RICH) detector, we were able to extract charge-separated pion and kaon multiplicities. Significant effort was put reducing the model dependence of the result by tuning the used MC generator and using an unfolding method to correct for experimental inefficiencies and migration of events due to both radiative and detector smearing.

Keywords: HERMES, fragmentation, hadron multiplicity
PACS: 13.87.Fh

INTRODUCTION

The confinement principle states that partons cannot exist as free particles. Therefore when a highly energetic probe hits one of the partons inside a nucleon, it will break free from the nucleon, forming new hadrons from its color field link with the nucleon remnant. It is interesting to study this process at moderate energies at which perturbative QCD and factorization are not yet fully established and tested. With a positron beam energy of 27.6 GeV and a fixed, gaseous hydrogen target, the HERMES experiment [1] provides an ideal setup to undertake this study at $\sqrt{s}$ of about 7 GeV. It is located on the HERA storage ring at DESY, Hamburg. The analysis briefly presented here displays the extraction of flavor separated multiplicity distributions, defined in this way :

$$\frac{1}{\sigma^{DIS}} \cdot \frac{d\sigma^{ep\to e'hX}(z,Q^2)}{dz} = \frac{\sum_f e_f^2 \int_0^1 dx\, q_f(x,Q^2) D_f^h(z,Q^2)}{\sum_f e_f^2 \int_0^1 dx\, q_f(x,Q^2)}. \tag{1}$$

In this equation $q_f(x,Q^2)$ represent the parton distribution functions and $D_f^h(z,Q^2)$ the fragmentation function of the parton of flavor f into a hadron of type h. The observable $z = E_h/\nu$ represents the energy fraction carried away by the hadron considered. Of course Q^2 is the exchanged photon virtuality and x the momentum fraction of the struck quark.

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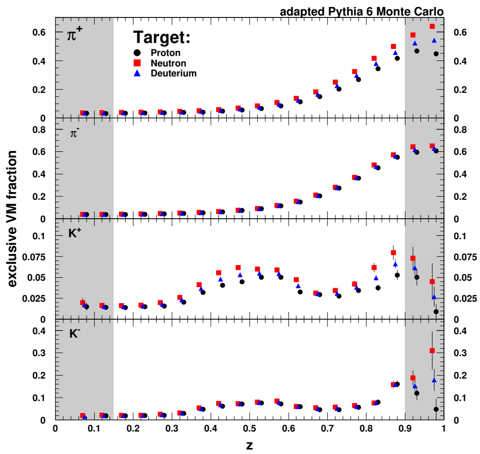
EXPERIMENTAL HADRON MULTIPLICITIES

At the first stage in the analysis a hadron PID correction was applied that accounts for misidentification of hadrons by the RICH [2] detector. From a GEANT description of the RICH, a matrix $\mathbf{P}$ was extracted in which each element $\mathbf{P}_t^i$ represents the probability that a particle of type t was identified as type i, thus $\vec{I} = \mathbf{P} \cdot \vec{N}$ in which $\vec{I}$ and $\vec{N}$ are respectively the vectors with identified particles and real particles. Inversion of this matrix $\mathbf{P}^{-1}$ results in a weight to obtain the true particle flux for each identified particle type i . The $\mathbf{P}$ matrix depends on the momentum of the hadrons and the event topology. The contribution to the systematic uncertainty from this correction results from the non-perfect knowledge of the response of the RICH detector. Two different settings were used in the RICH Monte Carlo description, one for $\beta = 1$ particles tuned the Čerenkov angle and photon yield distributions, while the second uses information from decaying particles (ϕ, K_S, Λ^0) from both data and Monte Carlo. The difference between the two resulting $\mathbf{P}$ matrices is taken as a measure for the systematic uncertainty.

Next, two sources of background were identified and corrected for. Positrons from e^+e^- pair production that ended up in the DIS sample were corrected for by subtracting the oppositely[2] charged leptons within the DIS sample. This correction is small and increases total experimental hadron multiplicity by 1 to 1.5 %. The second identified source of background comes from the decay of diffractively produced vector mesons like ρ^0 or ϕ. For this the PYTHIA6 generator [3] was taken and adapted with QED radiative corrections and tuned to fit HERMES kinematic distributions. Especially at low Q^2 and high z contributions can reach 40 to 50 % of pions mainly coming from diffractively produced ρ^0, whereas for kaons the contribution is limited to about 10 %. This is shown in figure 1. The gray area is not used in the rest of the analysis. This correction was applied following the philosophy that the production process for these hadrons is totally different from quark fragmentation. However the final results will be presented with and without this background subtracted.



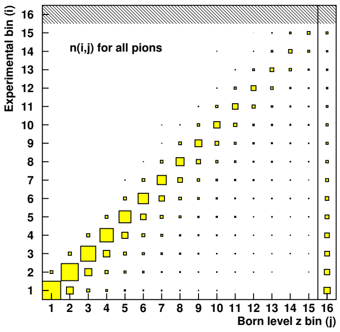
1: Exclusive VM fraction vs. z

SMEARING AND ACCEPTANCE CORRECTION

The following step is to correct these experimental multiplicity distributions for smearing and acceptance. In order to have a clear treatment of the uncertainties involved, we keep track of the smearing between kinematical bins by means of a smearing matrix

[2] With respect to the beam charge.

$S(i,j) = n(i,j)/n^B(j)$, of which each element represents the flow of events from a Born level bin j to an experimental bin i. It is defined as the migration matrix $n(i,j)$ normalized by the Born level distribution $n^B(j)$. Since both of these quantities are extracted from Monte Carlo using the same model, the dependence on this input model is greatly reduced. Figure 2 displays the migration matrix $n(i,j)$ for the 15 z bins from 0.15 to 0.9 as used in the analysis. The last j bins represents events smeared from outside the Born level sample into the experimental sample. One can clearly see the asymmetric shape of the migration matrix. This is due to QED radiative corrections which only work in one direction of ν (and thus z). The change in kinematics due to detector smearing is much smaller in size and works in both directions. The model dependence of this approach was checked by using different tunes for the JETSET fragmentation model in the Monte Carlo. The variation was found to be well inside the assigned systematic uncertainty. Normalizing to a 4π Born distribution $n^B(j)$ also takes into account the HERMES acceptance. Being a forward detector with an gap of 80 mrad around the beam pipe, the HERMES experiment is limited in its acceptance, it nevertheless samples the kinematical phase space well enough to fix the dynamics.



2: The migration matrix

RESULTS & CONCLUSION

The resulting hadron multiplicities were evolved to a Q_0^2 of 2.5 GeV^2/c^2. The multiplicity distributions versus z are displayed in figure 3, both with and without the correction for exclusive vector meson production. When evolving to a scale of 25 GeV^2/c^2 this data is found well in agreement with previously published fragmentation functions by the EMC experiment [4]. Finally the Q^2 dependence of the multiplicities was investigated. Figure 4 shows this compared to a parameterization by S. Kretzer [5]. One can see that the agreement is good. The other plot the same figure shows the residual x dependence compared to data. This analysis observed a much weaker residual x dependence than the EMC data or previous HERMES data [6]. This can be attributed to a much better understanding of the Monte Carlo and the corrections involved. From this analysis no signs of strong factorization breaking can be observed for the HERMES kinematical regime.

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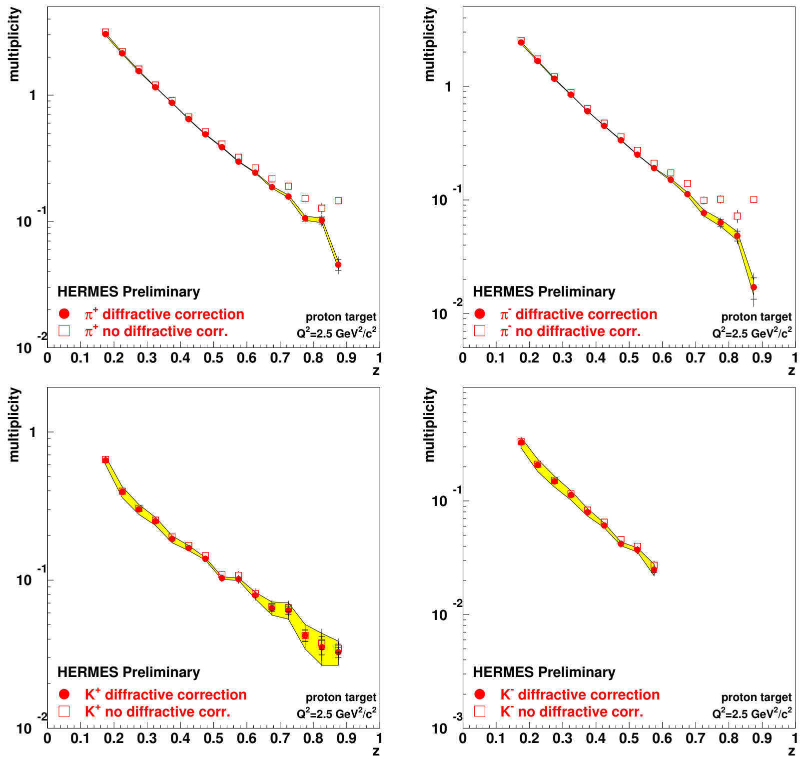

FIGURE 3. Multiplicity distributions on a proton target for π^+, π^-, K^+ and K^- versus z. All the data has been evolved to $Q^2 = 2.5$ GeV^2/c^2, the closed symbols represent the data with the exclusive VM correction in.

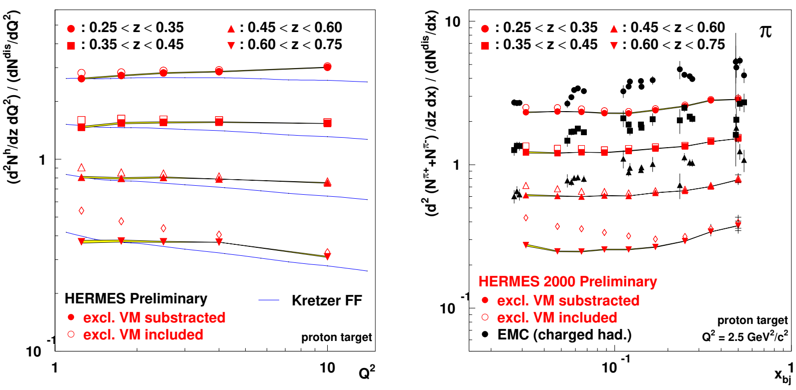

FIGURE 4. The Q^2 dependence for the total hadron multiplicity compared to the Kretzer parameterization (left). Right is shown the residual x dependence of the total pion multiplicity, compared to previously released EMC data [4] evolved to Q^2 of 2.5 GeV^2/c^2. The HERMES points are connected to the systematic uncertainty bands.