Charged hadron multiplicities and quark fragmentation functions from COMPASS

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On behalf of the COMPASS Collaboration

• Charged hadron multiplicities
• Quark fragmentation functions into pions from LO fit
• Outlook
**COMPASS at CERN**

Fixed target
160-200 GeV muon beam and 190 hadron beams from CERN SPS
→ Multipurpose setup

Polarized muon beam
& polarized target: d, p

Nucleon spin structure

Hadron beam $\pi / K / p$
& LH$_2$ or nuclei

Meson spectroscopy
$\pi, K$ polarizabilities

Future:
GPDs from DVCS
TMDs from Polarized Drell-Yan

Hadron beam $\pi / K / p$
\& LH$_2$ or nuclei

Polarized muon beam
& polarized target: d, p

Nucleon spin structure

**Future:**
GPDs from DVCS
TMDs from Polarized Drell-Yan
Quark Fragmentation Functions (FF)

- Non perturbative objects
- Process independent
- Needed to access strange quark polarization $\Delta s$ from polarized SIDIS. Strange quark FF = largest uncertainty in this extraction.

Data sensitive to FFs exist from $e^+e^-$ and pp reactions, but are unsufficient for good flavour separation and at too high $Q^2$

→ extract FFs from unpolarized COMPASS SIDIS data
Quark FFs from SIDIS

Measurement of multiplicities of $\pi$, K, p in SIDIS

$\mu^+d \rightarrow \mu^+h\pm X$

Hadron multiplicity = mean number of hadrons $h$ per DIS event

$$z = \frac{E_h}{(E_\mu - E_\mu')}$$

PDFs depend on $x$, while FFs depend on $z$

$$\frac{dM^h(x, Q^2, z)}{dz} = \sum_q e^2_q f_q(x, Q^2) D^h_q(z, Q^2)$$

PDFs depend on $x$, while FFs depend on $z$

$$\sum_h \int_0^1 zD^h_q(z) \, dz = 1$$

Data can be obtained in a fine binning in $x$, $z$, $Q^2$

→ Input to global QCD analyses to extract quark FFs
Data analysis - hadron multiplicities

- 3 Weeks of 2006 data (1/4 of total stat.)
  $^6$LiD target: isoscalar

- Kinematic cuts:
  - **Inclusive events:**
    - $Q^2 > 1 \text{ GeV}^2/c^2$
    - $0.1 < y < 0.7$
    - $0.004 < x < 0.7$

- **Hadrons:**
  - $0.2 < z < 0.85$
  - $10 < p_h < 40 \text{ GeV}/c$

- **Analysis:**
  - Calculate **raw** multiplicities of $h^{+-}$, $\pi^{+-}$ and $K^{+-}$
    - in 3D-binning: $(x, y, z)$, $<Q^2>$ evaluated in each bin
    - RICH likelihood cuts are used for identification
  - Apply corrections:
    - Efficiency/purity of RICH detector for $\pi/K$ identification
    - Spectrometer acceptance
      - including efficiency of detectors and event reconstruction
    - Electron contamination of $\pi$ sample
    - Diffractive vector meson production $\rho^0$ and $\phi$

Data cover $5 < W < 17 \text{ GeV}$
RICH performance matrices

Need to evaluate absolute efficiency / purity of RICH detector

- "pure" $\pi$, $K$ and $p$ samples, well identified from parent decays:

  - Look at RICH responses

  $\rightarrow$ Probabilities $P$ of identification and misidentification of $\pi^{+/−}$, $K^{+/−}$ and $p$

Example for positive particles

$P(h^+ → π^+)$ vs $p_h$ in one $θ$ bin:

$P$ in $(p_h, θ)$ bins

- $p_h$: momentum of hadron
- $θ$: angle at RICH entrance

Measured

"True"
Acceptance calculation

Includes geometric acceptance plus detector and reconstruction efficiency

\[ A^h(x, y, z) = \frac{M_r^h(x, y, z)}{M_g^h(x, y, z)} \]

\( h = h^+, h^-, \pi^+, \pi^-, K^+, K^- \)
Spectrometer acceptance for $h^+$ and $h^-$

Prelim. results from MC simulation: $A(z)$ in 29 (x-y) bins

- $A^{h^+} \approx A^{h^-} \approx 0.6$
- $h^+$
- $h^-$
Contribution from diffractive meson production

The data sample includes SIDIS events but also π and K from diffractive meson production, without quark hadronization.

Main VM: $\rho^0$ and $\phi$

\[ \gamma^* N \rightarrow \rho^0 N \rightarrow \pi^+ \pi^- N \]
\[ \gamma^* N \rightarrow \Phi N \rightarrow K^+ K^- N \]
Contribution from diffractive meson production

- MC simulation, using LEPTO for SIDIS and HEPGEN for VM production

- In total, contribution from VM small: few %

However in some bins, it reaches:
- 40% for $\pi$ (high $z$, low $Q^2$)
  there, $\pi$ multiplicities are very small
- 20% for $K$ ($z\sim0.6$, low $Q^2$)

- Multiplicity data will be published with and without correction

Ex: Correction for contribution of $\pi$ from $\rho^0$
in the data sample, vs $z$, in 35 (x,y) bins

$\pi^+$ and $\pi^-$ multiplicities vs $z$ in $(x,y)$ bins

**COMPASS prelim. (DIS-2013, N.Makke)**

- ~500 data points for $\pi$
- Strong $z$ dependence
- $M\pi^+ \sim M\pi^-$

Here shown without $\rho^0$ subtraction

Systematics dominated by uncertainty on acceptance (5%) and RICH.

NB- Also measured: $p_T$ dependence (see talk of N.Makke) and 2h multiplicities
**K^+ and K^- multiplicities vs z in (x,y) bins**

**COMPASS prelim. (DIS-2013, N.Makke)**

- ~500 data points for K
- Strong z dependance
- \(M_{K^+} > M_{K^-}\)

Here shown without \(\rho^0\) subtraction
Quark FFs into $\pi$, from COMPASS LO fits

Assume isospin and charge symmetry:

$$D_{\text{fav}}^{\pi^+} = D_{u}^{\pi^+} = D_{d}^{\pi^+} = D_{d}^{\pi^-} = D_{u}^{\pi^-}$$

$$D_{\text{unf}}^{\pi^+} = D_{d}^{\pi^+} = D_{u}^{\pi^+} = D_{u}^{\pi^-} = D_{d}^{\pi^-}$$

Assume also $D_s^{\pi^+} = D_s^{\pi^-} = D_{\text{unf}}^{\pi^+}$

Choose functional forms for FFs ($z$); use DGLAP.
Fit $\pi^+$ and $\pi^-$ multiplicities and extract the 2 independent FFs:

Next step: Fragmentation functions into kaons $D_s^{K^+}$ and $D_s^{K^-}$ starting from kaon multiplicities

(\text{D. Hahne DPG-2014 and N. du Fresne von Hohenesche. DIS-2014})
Summary

**Multiplicities for** $h^+, h^-, \pi^+, \pi^-, K^+, K^-$

in a fine binning of $x, y, z$; $5 < W < 17$ GeV

Important input to global QCD fit of FFs at NLO

**Quark FF into pions from LO fit of $\pi^+, \pi^-$ multiplicities**

$D_{\text{fav}}^\pi$ & $D_{\text{unfav}}^\pi(z, Q^2)$: Promising results already at LO

**In progress**

Finalize pion and kaon multiplicities with improved MC and RICH treatment

Extract quark FF into kaons

Analyze data on H$_2$ target (2012) → more input for flavor separation

**Future**

2016-2017: large set of proton data

(in parallel to GPD program: $\mu$ beam, H$_2$ target & upgraded RICH detector).
Spares
Systematic uncertainties

- Acceptance:
  - different sets of PDF in Lepto
  - different JETSET tunings
  \[ \approx 5\% \]

- RICH PID efficiency
  - pions: 1\% - 3\%
  - kaons: 5\% - 10\%

- Diff. \( \rho^0 \) and \( \phi \) correction
  - 30\% theoretical uncertainty on HEPGEN cross-section
    - 12\% max uncertainty on correction

- Electron correction
  - 25\% MC/data difference \( \rightarrow \) 50\% conservative syst. error
Quark FFs into $\pi$, from COMPASS fits

N. Dufresnes at DIS-2014

Starting from $\pi$ multiplicities, extract 2 FFs.

\[ D_{\text{fav}}^{\pi^+} = D_{u}^{\pi^+} = D_{\bar{d}}^{\pi^+} = D_{d}^{\pi^-} = D_{\bar{u}}^{\pi^-} \]
\[ D_{\text{unf}}^{\pi^+} = D_{d}^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_{\bar{d}}^{\pi^-} = D_{\bar{u}}^{\pi^-} \]

And assuming $D_{\text{unf}}^{\pi^+} = D_{s}^{\pi^+} = D_{s}^{\pi^-}$

\[ M^{\pi^+}(x, Q^2, z) = \frac{(4(u + d) + u + d)D_{\text{fav}} + (u + d + 4(\bar{u} + \bar{d}) + 2(s + \bar{s})D_{\text{unf}}}{5(u + d + u + d) + 2(s + \bar{s})} \]
\[ M^{\pi^-}(x, Q^2, z) = \frac{(u + d + 4(\bar{u} + \bar{d}))D_{\text{fav}} + (4(u + d) + \bar{u} + \bar{d} + 2(s + \bar{s})D_{\text{unf}}}{5(u + d + \bar{u} + \bar{d}) + 2(s + \bar{s})} \]

$u, d, \bar{u}, \bar{d}, s, \bar{s}(x, Q^2) =$ parton distribution functions (MSTW08)

LO fit of experimental multiplicities:

- Functional form: $zD_{\text{fav}} = zD_{\text{unf}} = Nz^{\alpha}(1-z)\beta[1 + \gamma(1-z)^{\delta}]$ at a given $Q^2_0$

- Evolution from $Q^2_0$ to $Q^2$ of data points with DGLAP
Sum $M(K^+) + M(K^-)$

COMPASS PRELIMINARY

N. Makke, DIS 2013
Electron contamination of pion sample

Electrons can be misidentified as pions

- 3 - 8 GeV/c:
  - e/π separation possible
  - difference MC/data 25%

- 10 - 40 GeV/c (analysis range):
  - Contamination evaluated by MC
  - 50% systematic uncertainty

Correction of pions yields: <1% (high z) to 5% (low z)