Overview: Pion and Kaon Multiplicities in Muon-Nucleon Scattering from 2006 Data

Bonn Xmas Meeting 2013

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On behalf of the COMPASS collaboration

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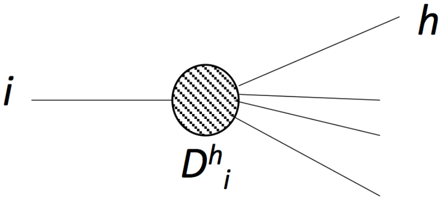
Fragmentation Functions

- Hadronisation in QDC
- Fragmentation functions D_i^h
- Hadronisation of quark with flavour i to hadron h
- Normalised, universal and process independent
- Favoured and unfavoured FFs



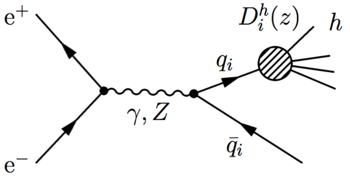
$$\sum_h \int_0^1 D_i^h(z)\, dz = 1$$

$$D_{fav.} >> D_{unfav.}$$

How to Access Fragmentation Functions

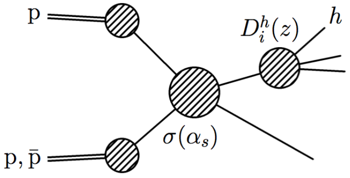
- e^+e^- annihilation

Precise and clean data
Only depends on FF
$q\bar{q}$ fragmentation not distinguishable
Charge sum
(LEP, BELLE,...)



- pp collision

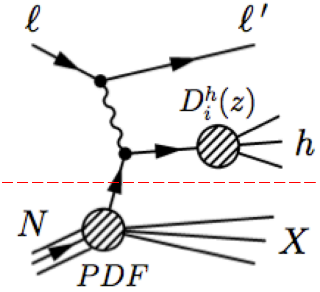
Gluon FF
Strongly dependant on PDFs
Difficult theoretical description
(RHIC, Fermi Lab., ...)



Fragmentation Functions from SIDIS

- Semi-Inclusive Deep Inelastic Scattering $\Rightarrow \ell + N \xrightarrow{\gamma^*} \ell' + h + X$

Allows flavour separation
Wide coverage in x and Q^2
(COMPASS, HERMES,...)



$$Q^2 \equiv -\mathbf{q}^2 = -(\mathbf{k}-\mathbf{k}') \overset{\text{lab}}{\simeq} 4EE' \sin\frac{\theta}{2}$$

$$x \equiv \frac{Q^2}{2\mathbf{P}\cdot\mathbf{q}} \overset{\text{lab}}{=} \frac{Q^2}{2M\nu}$$

$$y \equiv \frac{\mathbf{P}\cdot\mathbf{q}}{\mathbf{P}\cdot\mathbf{k}} \overset{\text{lab}}{=} \frac{\nu}{E}$$

$$z \equiv \frac{\mathbf{p_h}\cdot\mathbf{P}}{\mathbf{q}\cdot\mathbf{P}} \overset{\text{lab}}{=} \frac{E_h}{\nu}$$

The Strange Quark Helicity Density

Strangeness contribution to long. spin:

$$\Delta S = \int dx \, [\Delta s(x) + \Delta \bar{s}(x)]$$

- From inclusive measurements:

$g_1(x,Q^2)$ for proton and deuteron
NLO QCD fits

$\Delta s + \Delta \bar{s} = -0.08 \pm 0.01_{stat.} \pm 0.02_{sys.}$

Incl - Phys. Lett. B684 (2010) 216

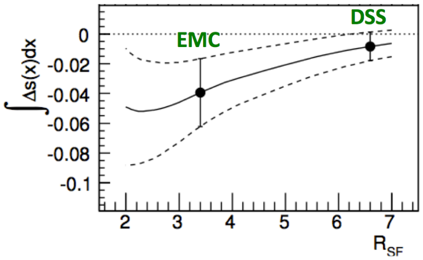
- From SIDIS (LO):

Semi-inclusive asymmetries
In combination of PDFs
And fragmentation functions

$\Delta s + \Delta \bar{s} = -0.02 \pm 0.02_{stat.} \pm 0.02_{sys.}$

SemiIncl - Phys. Lett. B693 (2010) 227

$$R_{SF} = D_{\bar{s}}^{K^+} / D_u^{K^+}$$



DSS - Phys. Rev. D75 (2007) 114010

EMC - Nucl. Phys. B321 (1989) 541

Multiplicities as Observables

- Factorisation theorem
- SIDIS cross section in leading-twist

Hard scattering cross section
Parton distribution function
Fragmentation functions

$$\sigma^{\mathrm{h}} = \sum_i \sigma^0 \cdot q_i(x) \cdot D_i^h(z, Q^2)$$

Extraction of FF from hadron multiplicities

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

Depends on the unpolarised parton distribution functions $q(x, Q^2)$

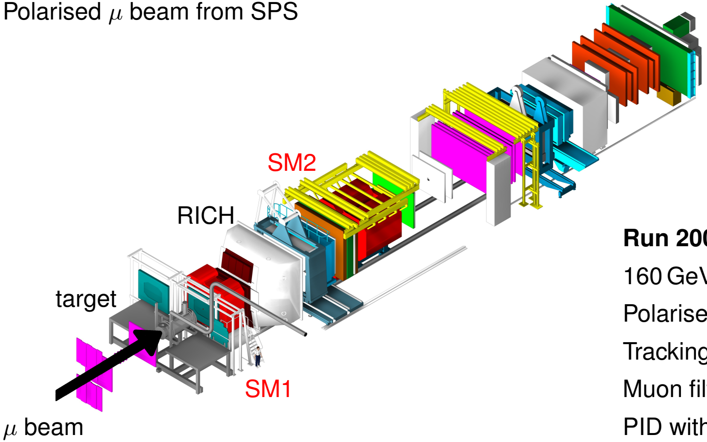
- Unpolarised up/down PDFs well known
- Strange PDFs poorly known

The COMPASS Experiment

COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

Fixed target experiment @CERN

Polarised μ beam from SPS



Run 2006:

160 GeV/c μ^+

Polarised ^{6}LiD target

Tracking

Muon filter for μ' ID

PID with RICH

CERN-PH-EP/2007-001 hep-ex/0703049

High acceptance, high beam flux and PID

DIS Selection

2006 data $\approx$ 700 runs (6 weeks)

- Rescale momentum function
- Best primary vertex with
  - PaAlgo::InTarget()
  - Target Cells Z cut -59 to -33, -20 to 32 and 39 to 67 (all cm)
  - PaAlgo::CrossCells()
- Outgoing μ' Incoming μ
- 140 < Beam energy < 180 GeV
- $Q^2 > 1\,GeV^2$
- 0.1 < y < 0.9
- 5 < W < 17 GeV
- BMS Chi^2 Cut flag
- Middle trigger correction
- Only OT and MT
- Radiative correction PaAlgo::GetRadiativeWeigth(x,y,2)

Hadron Loop

For unidentified hadron candidates:

- Loop over outgoing particles
- Reject μ'
- ZFirst > 350 cm and ZLast > 350 cm
- RICH cuts
  - $0.01 < \theta < 0.12$
  - RICH pipe cut
- PID with RICH
- z cut 0.2 < 0.85
- momentum cut 10 - 40 GeV for π
- momentum cut 12 - 40 GeV for K

Acceptance

Monte Carlo simulation

- Taking into account geometric acceptance of the apparatus
- Detector efficiencies

LEPTO generator with PDFs
JETSET for hadronisation
GEANT3 with COMPASS detector models

LEPTO extrapolation:
Not all bins are completly filled (cuts)
Fill up with LEPTO model

Old Method

Double ratio

$$Acc = \frac{N_{h\_rec}/N_{DIS\_rec}}{N_{h\_gen}/N_{DIS\_gen}} = \frac{M_{rec}(\text{from rec DIS})}{M_{gen}(\text{from gen DIS})}$$

As used in April 2013 release, but error estimation more complicated
Assumption: hadron and DIS events are independent

$A_h = \frac{N_{h\_rec}}{N_{h\_gen}}$ and $A_{DIS} = \frac{N_{dis\_rec}}{N_{dis\_gen}}$

$$\Delta Acc = \Delta(A_h/A_{DIS}) = A_h/A_{DIS} \times \sqrt{((\Delta A_h/A_h)^2 + (\Delta A_{DIS}/A_{DIS})^2)}$$

New Method

Single ratio

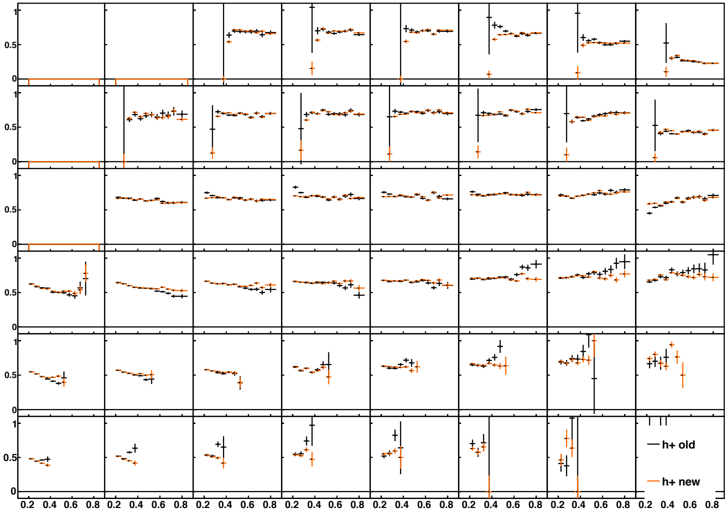
$$Acc = \frac{N_{h\_rec}(\text{from rec DIS})}{N_{h\_gen}(\text{from rec DIS})}$$

Advantage: Easier error estimation and muon acceptance is out

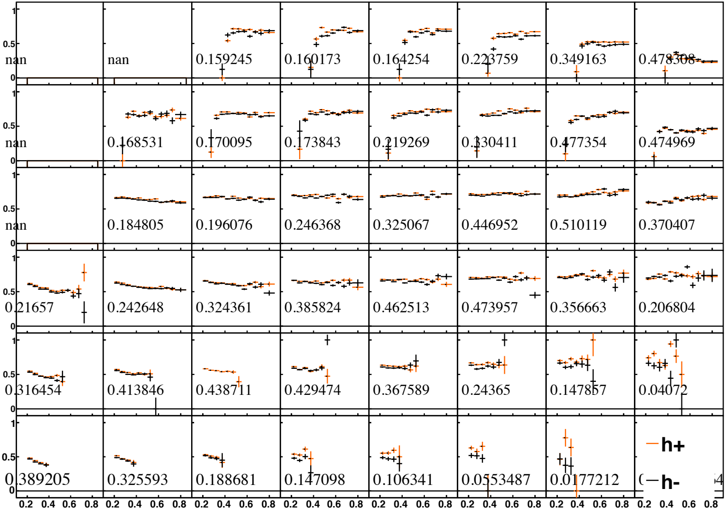
$$(\Delta Acc)^2 = \frac{(A+1)(G-A+1)}{(G+2)^2(G+3)}$$

with A for accepted events and G for generated events

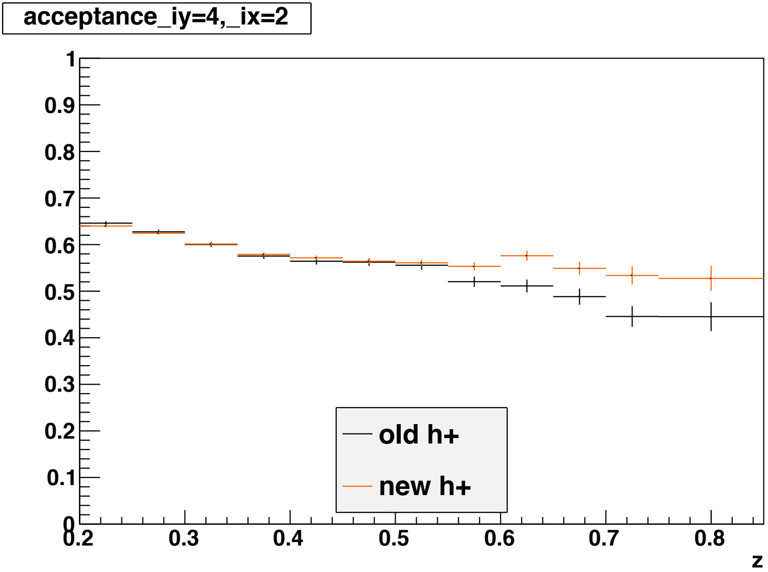
Comparison Old/New for h^{+}



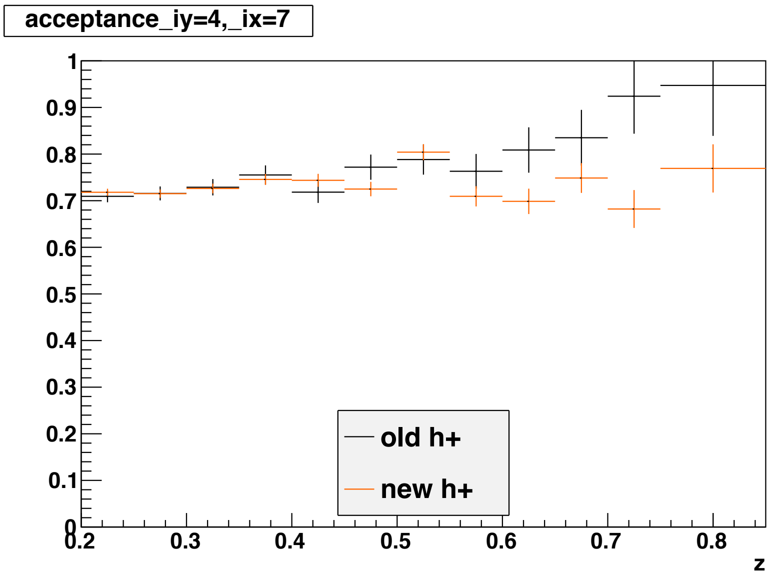
New for $h^{+/-}$ with muon acceptance



Closer Look 2,4



Closer Look 7,4



Acceptance Comparison

$$Acc = \frac{N_{h\_rec}/N_{DIS\_rec}}{N_{h\_gen}/N_{DIS\_gen}} = \frac{N_{h\_rec}(z)}{N_{h\_gen}(z)} \cdot \frac{N_{DIS\_gen}}{N_{DIS\_rec}}$$

vs.

$$Acc = \frac{N_{h\_rec}(z)(\text{from rec DIS})}{N_{h\_gen}(z)(\text{from rec DIS})}$$

Where the blue numbers are the same!
Why do we see a z-dependence?
Looking at acceptance(ϕ_μ) in correlation of the hadron angle and z
Under construction, discussion with DVH

Correction and Uncertainties

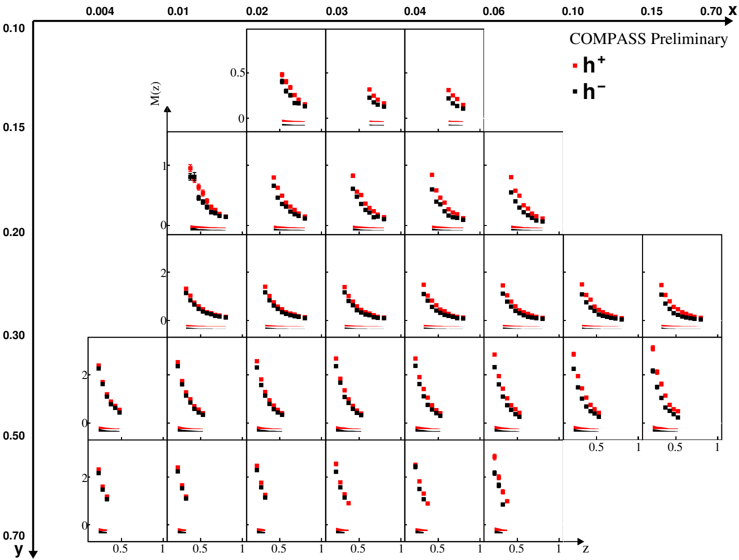
Radiative Corrections
QED radiative effects with TERAD

Muon dependent systematics
Muon acceptance and systematic uncertainties cancel out

MC model dependence
Using different quark fragmentation models in JETSET
Different parton distribution functions in LEPTO
$\approx$ 5%

LEPTO dependence
Effects in smaller and larger z region
Only using bins where LEPTO contribution is small (<10%)
Small systematic uncertainty

Unidentified Hadron Multiplicities



Rich Unfolding

Experimental method to extract RICH efficiencies and missidentification
Tagging hadrons from known decays

$\Lambda^0 \rightarrow p + \pi^-$ for protons, $K_s^0 \rightarrow \pi^+ + \pi^-$ for pions and $\phi \rightarrow K^+ + K^-$ for kaons

RICH table example

- $\pi^+ \rightarrow \pi^+ \approx 98\%$
- $\pi^+ \rightarrow K < 2\%$
- $\pi^+ \rightarrow p < 1\%$

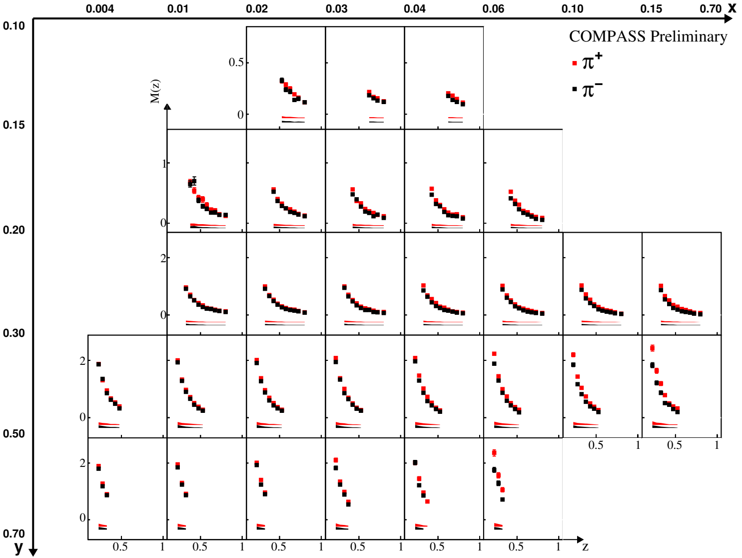
Hadron momentum dependence

$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \begin{pmatrix} P_\pi^\pi & P_K^\pi & P_p^\pi \\ P_\pi^K & P_K^K & P_p^K \\ P_\pi^p & P_K^p & P_p^p \end{pmatrix} \begin{pmatrix} T_\pi \\ T_K \\ T_p \end{pmatrix}$$

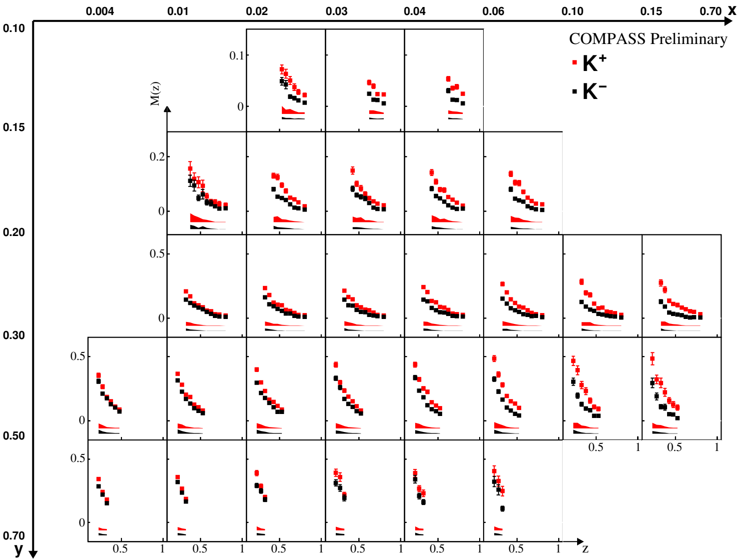
$$\vec{T} = \vec{I} \cdot P^{-1}$$

Systematics:
1% - 3% for pions
5% - 10% for kaons

Pion Multiplicites



Kaon Multiplicites



The Sum of Charged Kaon Multiplicities

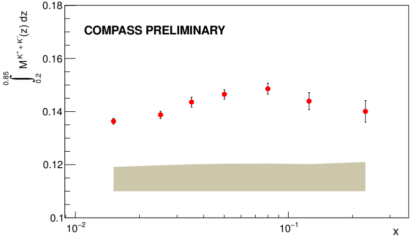
Dependence on strange quark distribution s(x) and $D_s^K(z)$

$$\int M^{K^+ + K^-}(z)dz = \frac{1}{dN^{DIS}/dx}\frac{dN^K}{dx} = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x) + 2S(x)}$$

Expanding towards $\frac{S(x)}{Q(x)}$:

$$\propto 1 + \frac{S(x)}{Q(x)}\left(\frac{D_S^K}{D_Q^K} - \frac{2}{5}\right)$$

Expecting ↑ S(x) with ↓ x



No visible x dependence→ small D_S^K?

Summary and Outlook

- 2006 run at COMPASS with ^{6}LiD target and 160 GeV μ^+ beam
- Measured preliminary pion and kaon multiplicities in x, z, and y
- Final radiative corrections
- Estimation for exclusive vector meson production
- More statistic
- More MC
- QCD fits of FFs

- 2012 run on liquid hydrogen
- >2015 long runs with $\approx 300\,\mathrm{pb}^{-1}$
- Dihadron FFs

Thanks for your attention