Strangeness in the nucleon
Strange quark fragmentation functions

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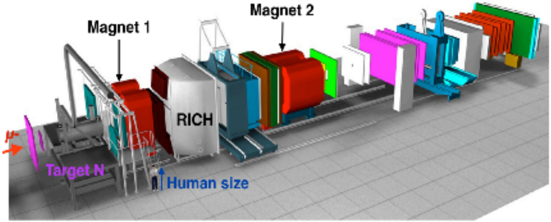
Contents

COMPASS experiment at CERN

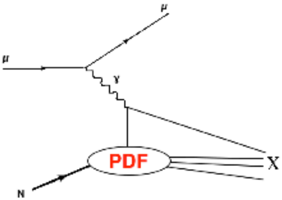
- Fixed target experiment, nucleon structure studies. Muon beam at 160 GeV, high energy Deep Inelastic Scattering in order to probe partons $\mu d \to \mu h X$
- Polarised muons (spins aligned, not used in this study) on polarised nucleon target $\to$ nucleon spin physics.
- Analysis of scattered muons and resulting particles in 50 m two-part spectrometer.
- Separation π/K done by RICH (Ring Imaging Cerenkov).



Context

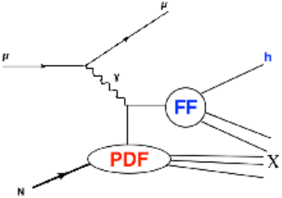
DIS

- DIS : Deep Inelastic Scattering $\mu N \to \mu X$
- High energy to probe partons from nucleon (u,d,s,g..) and parametrise the distributions via Fonctions de Distribution de Partons (PDFs).
- Variables : Q^2 (scale), x (Bjorken-x)



SIDIS

- SIDIS : Semi-Inclusive DIS (observation of a hadron in the final state) $\mu N \to \mu h X$
- h tags the quark flavour (eg. $K^+(u\bar{s})$).
- Variables : Q^2, x, z ($\frac{E_h}{E_{\gamma^*}}$)



- Sensitive to PDFs and partons fragmentation functions (FF).
- FF = probability for a parton (quark or gluon) to hadronise.
- PDF, FF = Universal quantities. Can describe several processes.

Goal and motivation

Goal

Determine the quark FF into kaons after SIDIS :

- Needed for strangeness/spin studies
- Needed as universal quantity

Motivation

- Not enough measurements
- Controversy about the contribution of the spin of the strange quark to the proton spin (DIS/SIDIS results).

Parton Distribution Functions, Fragmentation Functions, Hadron Multiplicities

Parton Distribution Functions (PDFs)

- Parametrisation of the probability density of finding a parton q with a fraction x of $p_{||}$ of the nucleon N.
- Obtained by fits to DIS experimental data.

Quark fragmentation functions (FFs)

- Probability density of finding a hadron h with a certain energy fraction z of the struck quark q at a given Q^2.
- Can be measured in several processes, including SIDIS.

Hadron Multiplicities

- Mean number of hadrons produced per inclusive DIS event.

Multiplicities, PDFs and FFs

Link between FFs, PDFs and multiplicities

Multiplicities = convolution of *PDFs* and *FFs*. Expressed at QCD LO as :

$$M^h(x, z, Q^2) = \frac{\sum_q e_q^2\, q(x, Q^2)\, D_q^h(z, Q^2)}{\sum_q e_q^2\, q(x, Q^2)} \tag{1}$$

With q = (u,d,s,..) and h=π,K,..
$q(x, Q^2)$ depends on x, $D_q^h(z, Q^2)$ on z $\rightarrow$ allows the FF extraction.

Method

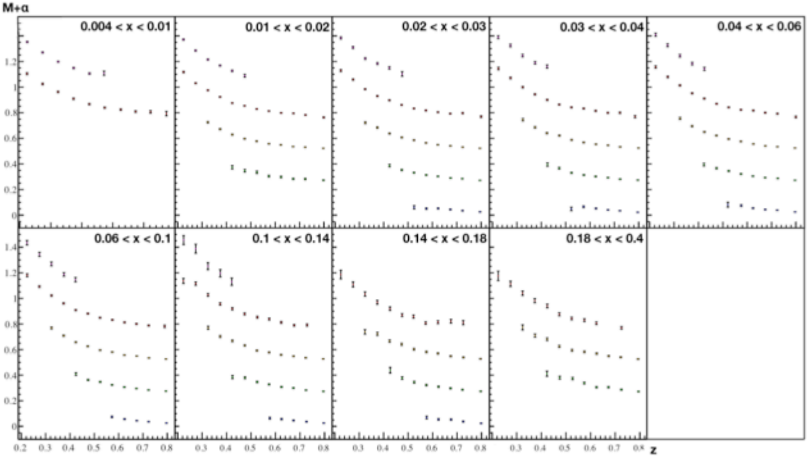
Extract FFs from measured hadron multiplicities and assumed known PDFs

Kaon multiplicities

- π data already analysed.
- Large amount of new Kaon data $\rightarrow$ Extract all $D_q^K(z, Q^2)$.

Input data : K^+ multiplicities $M^{K^+}(x, z, Q^2)$

- 300 data points scattered through 8 x bins, 12 z bins, 5 Q^2 bins (staggered vertically). Similar data for K^-.



- Coverage of large kinematic domain.

Fragmentation functions into kaons

- Kaons : $K^+(u\bar{s})$, $K^-(\bar{u}s)$
- Take account isospin and charge symmetries : 12 FFs $\rightarrow$ 3 FFs

Favoured : $D_{\text{fav}}^{K} = D_u^{K^+} = D_{\bar{u}}^{K^-}$

Strange : $D_{\text{str}}^{K} = D_{\bar{s}}^{K^+} = D_s^{K^-}$

Unfavoured : $D_{\text{unf}}^{K} = D_{\bar{u}}^{K^+} = D_s^{K^+} = D_u^{K^-} = D_{\bar{s}}^{K^-} = D_{\bar{d}}^{K^\pm} = D_d^{K^\pm}$

FF Extraction

$$M^h(x, z, Q^2) = \frac{\sum_q e_q^2\, q(x, Q^2)\, D_q^h(z, Q^2)}{\sum_q e_q^2\, q(x, Q^2)} \qquad (2)$$

Calculation of FFs

- 600 input data points (K^+ and K^-)
- 3 independent FFs
- $q(x, Q^2)$ from literature (LHAPDF)
- Fit to the data with chosen functional $D_q^h(z, Q^2_{ref}) = z^\alpha (1-z)^\beta$.
- Since data are at various Q^2, need Q^2 evolution :
  $D_q^h(z, Q^2 \neq Q^2_{ref}) = D_q^h(z, Q^2_{ref})+$ DGLAP Q^2 evolution.

Minimisation

C++ framework for minimisation

Framework around ROOT MINUIT

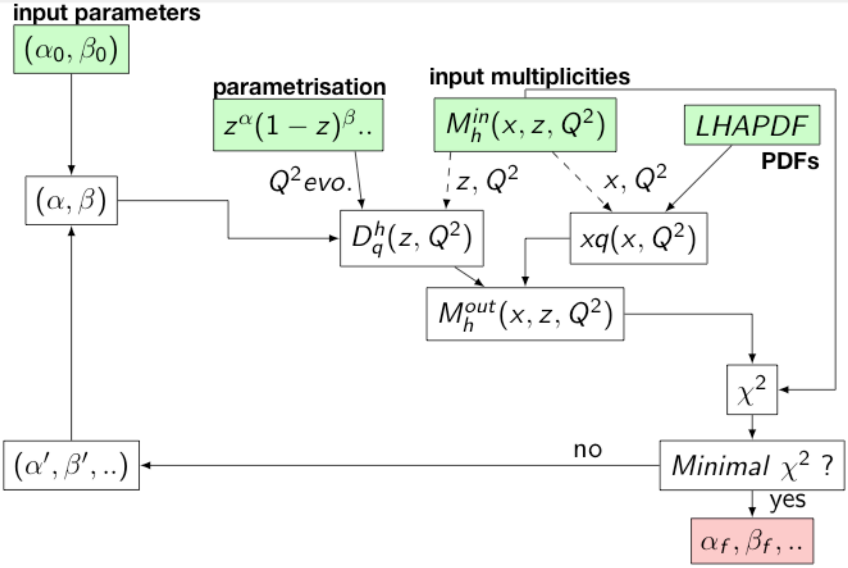
Notations

- M_{in} : measured multiplicities.
- M_{out} : calculated multiplicities with fitted FFs.
- σ : statistical errors on measured multiplicities.

Minimised function

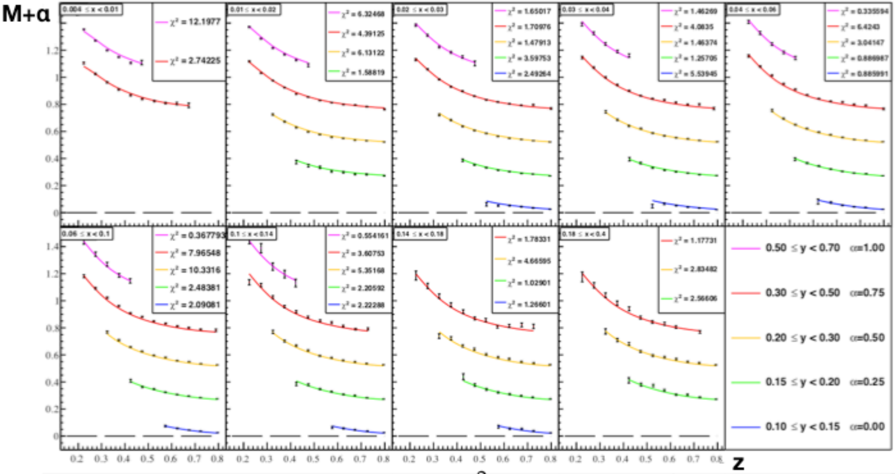
$$\chi^2 = \sum_{i,j,k} \left(\frac{M_{out}(x_i, z_j, Q^2_k) - M_{in}(x_i, z_j, Q^2_k)}{\sigma(x_i, z_j, Q^2_k)} \right)^2 \quad (3)$$

Algorithm diagram



Result from the simultaneous fit of K^+/K^- - K^+

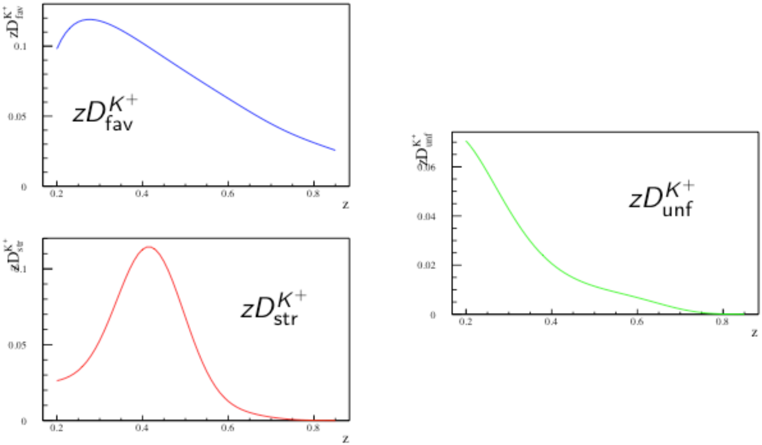
- 8 x bins, 12 z bins, 5 Q^2 bins (staggered vertically).



- Globally well fitted. The overal χ^2/dof is of 3.2 (systematic effects have not been taken into account).

Results of the FF extraction

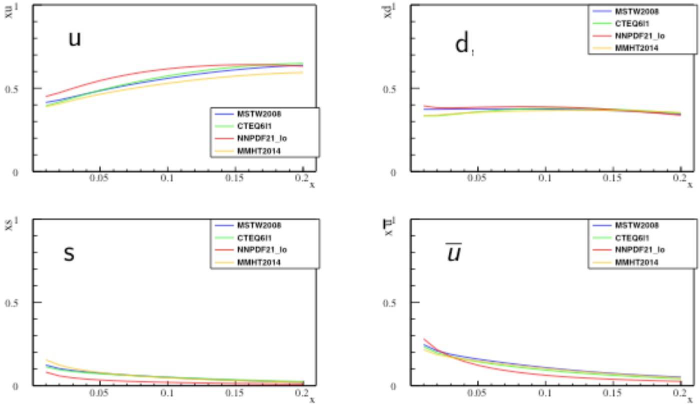
- LO plot of the extracted FFs : $D_q^K(z, Q^2)$ at $Q^2 = 3$ GeV.



- Favoured and unfavoured > expected (explained after).
- Strange and favoured have similar amplitude (explained after).

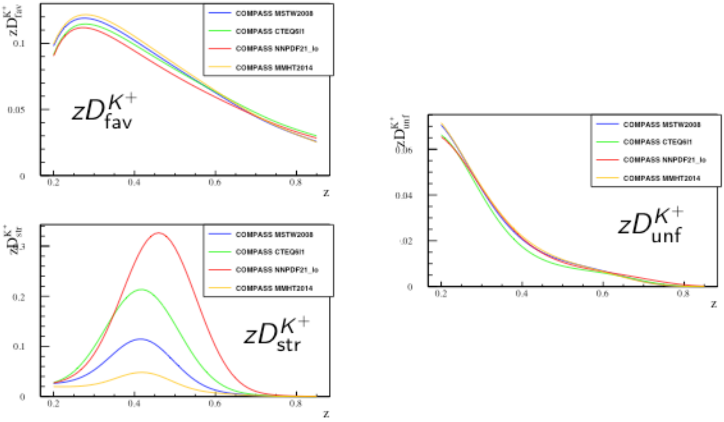
Systematic study 1 : choice of the PDF set

- u, d, s, $\overline{u}$ distribution for MSTW2008, CTEQ6, NNPDF21 and MMHT2014 sets from literature.



- u, d, $\overline{u}$ distributions within 10%.
- s distributions within a factor of 2.

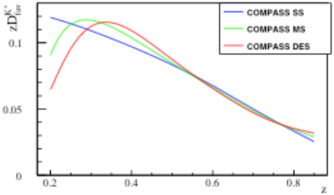
Systematic study 1 : FF extraction with different PDF sets

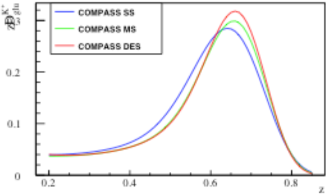


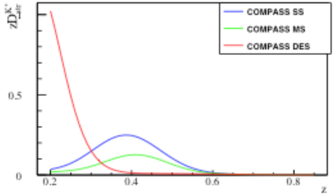
- Stable for favoured and unfavoured (within 10%).
- Unstable for strange as expected due to the choice of s(x).

Systematic study 2 : FF extraction with different functional forms

- Choice of three different functional forms for D_q^K.







SimpleKaon SS

- $zD_i(z) = \frac{N_i}{N_{norm,i}} z^{\alpha_i}(1-z)^{\beta_i}$ with $i = \{fav, unf, str, glu\}$.

MixKaon MS

- $zD_i(z) = \frac{N_i}{N_{norm,i}} z^{\alpha_i}(1-z)^{\beta_i}(1+\gamma_i(1-z)^{\delta_i})$ with $i = \{fav\}$.
- $zD_j(z) = \frac{N_j}{N_{norm,j}} z^{\alpha_j}(1-z)^{\beta_j}$ with $j = \{unf, str, glu\}$.

Div. Exp. Simple DES

- $zD_i(z) = \frac{N_i}{N_{norm,i}} z^{\alpha_i}(1-z)^{\beta_i} exp(\frac{-\gamma^2}{z})$ with $i = \{fav\}$.
- $zD_j(z) = \frac{N_j}{N_{norm,j}} z^{\alpha_j}(1-z)^{\beta_j}$ with $j = \{unf, str, glu\}$.

- Stable for favoured and unfavoured.
- Again unstable for strange.

Handling of uncertainties

Determination of error bands
taking into account statistical and systematic errors from data.

Statistical error band

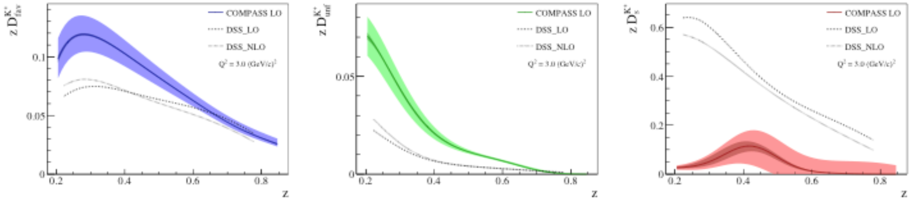
- Iterative method.
- Generation of 100 replicas choosing random multiplicity values within the error bars.
- Envelop of calculated FFs leads to the error band of the unmodified fit.

Systematic error band

- Similar work but varying points alltogether.

Error bands associated to the FFs

- Look at the calculated error bands.

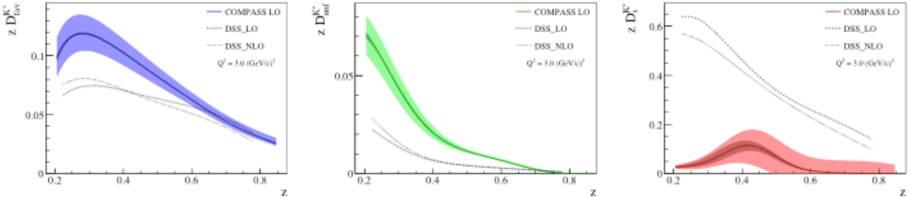


$zD^{K^+}_{\text{fav}}$ $zD^{K^+}_{\text{unf}}$ $zD^{K^+}_{\text{str}}$

- Narrow error band for favoured and unfavoured, wider for strange.
- Systematic band larger than statistical.

Comparison with other fits (DSS)

- Look at DSS (LO and NLO) which does not include COMPASS data.



$zD^{K^+}_{fav}$ $zD^{K^+}_{unf}$ $zD^{K^+}_{str}$

- Large differences with DSS. Not too big differences between DSS LO and NLO.
- Favoured and unfavoured >> DSS. Strange << DSS.
- DSS strange very high.

Analysis of complementary data

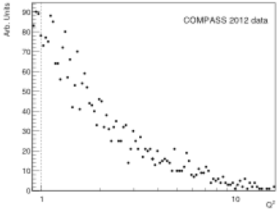
Context

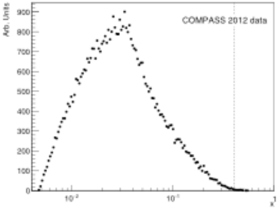
- Results on a deuteron target (^{6}LiD) not enough constrained for the strange quark FF.
- New data with a pure proton target (LH_2) $\rightarrow$ new set of equations.
- Amount of independent equations doubled $\rightarrow$ better constraints for the strange quark fragmentation function.

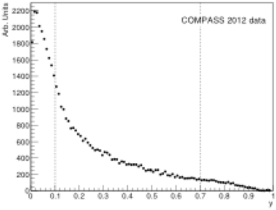
Method

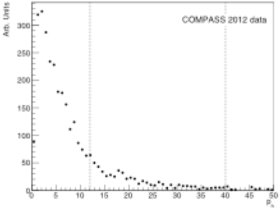
- Selection of DIS and SIDIS events with cuts on data.
- Correction to the data (eg. detector acceptance).

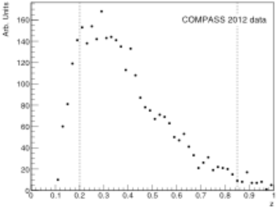
Analysis of complementary data











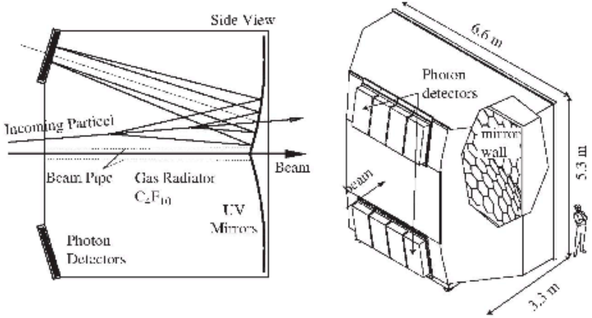
Good coverage of the kinematic space.

Conclusion and Prospects

- COMPASS data were used to extract quark fragmentation functions (FF) into kaons .
- Parametrisations of three independent quark FF into kaons extracted from fit. Studies on statistical and systematic uncertainties.
- Large discrepancy observed with existing results: "favoured" and "unfavoured" FFs significantly higher, "strange" FF is much smaller.
- Results shown at a recent conference and will be included in a publication of kaon data.
- New data on pure proton target should provide more constraints to the results. First results of this analysis are encouraging

Thank you for your attention !

RICH

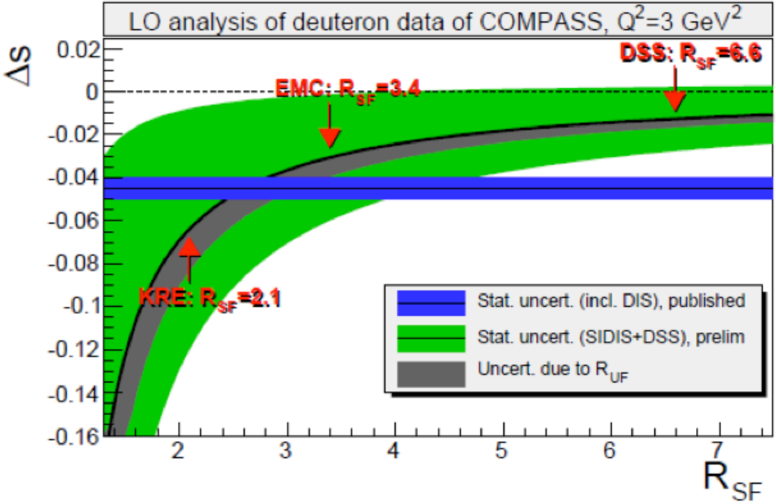


- Mirror system composed of several spherical mirrors covering area of almost 20 m^2.
- Focalises the Cerenkov photons onto two multi-wire proportional chambers (MWPCs) with segmented CsI photo-cathodes.
- These MWPCs are performing the identification and separation π/K.

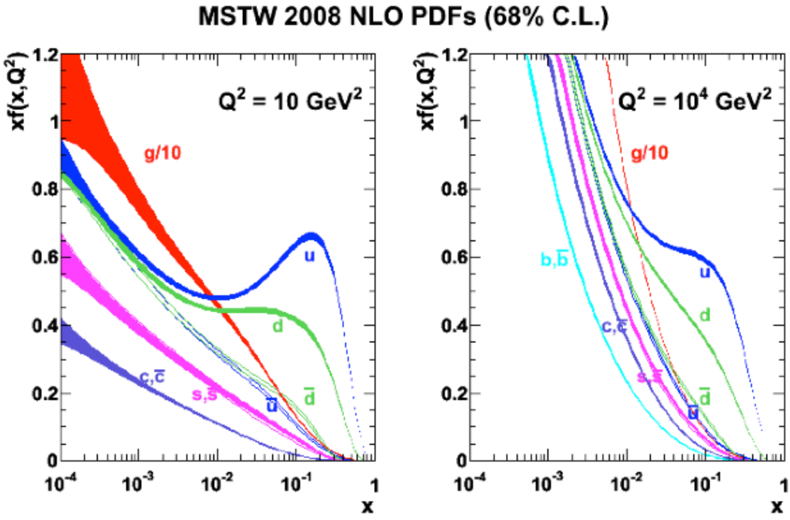
Strange spin - DIS/SIDIS results

- Negative Δs from DIS data.
- Δs compatible with zero in measured range for SIDIS data $\rightarrow$ uncertainties on quark fragmentation functions.
- With our work, if we consider our strange FF good $\rightarrow$ results for DIS and SIDIS agree.
- Need more data to confirm this result.

Strange spin - DIS/SIDIS results



PDF - Q^2 scale


MSTW 2008 NLO PDFs (68% C.L.)
xf(x,Q²)
Q² = 10 GeV²
g/10
u
d
d̄
ū
s,s̄
c,c̄
x
Q² = 10⁴ GeV²
b,b̄

Error bands associated to the FFs