Evaluation of Δq and Extraction of Fragmentation Functions from Charged Kaon Production at COMPASS

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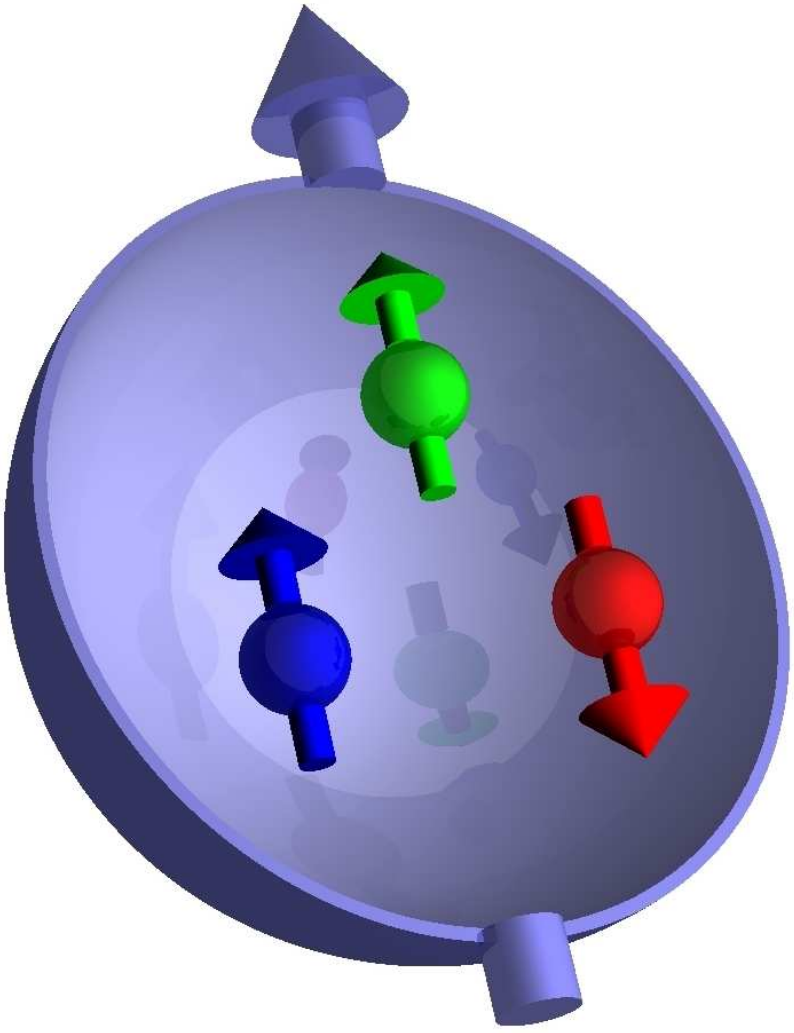
COMPASS

Contents

1. Introduction
2. The Extraction of Quark Helicity Distributions
3. The Influence of Fragmentation Functions
4. Extracting Fragmentation Functions from Kaon Multiplicities
5. Summary and Outlook

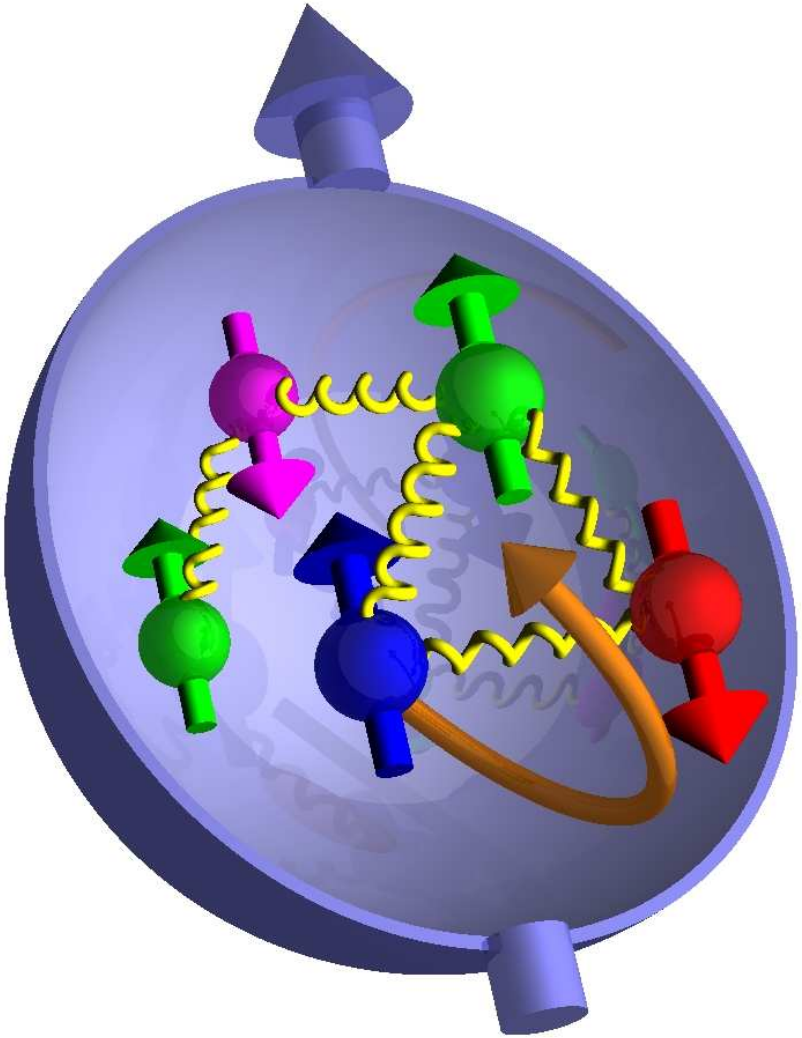
Background: Nucleon Spin Distribution



Spin contributions
(Static Quark Model):

- Valence quarks (u, d)

Background: Nucleon Spin Distribution



Spin contributions (QCD):

- Valence- and Sea quarks
- Gluons
- Orbital angular momentum

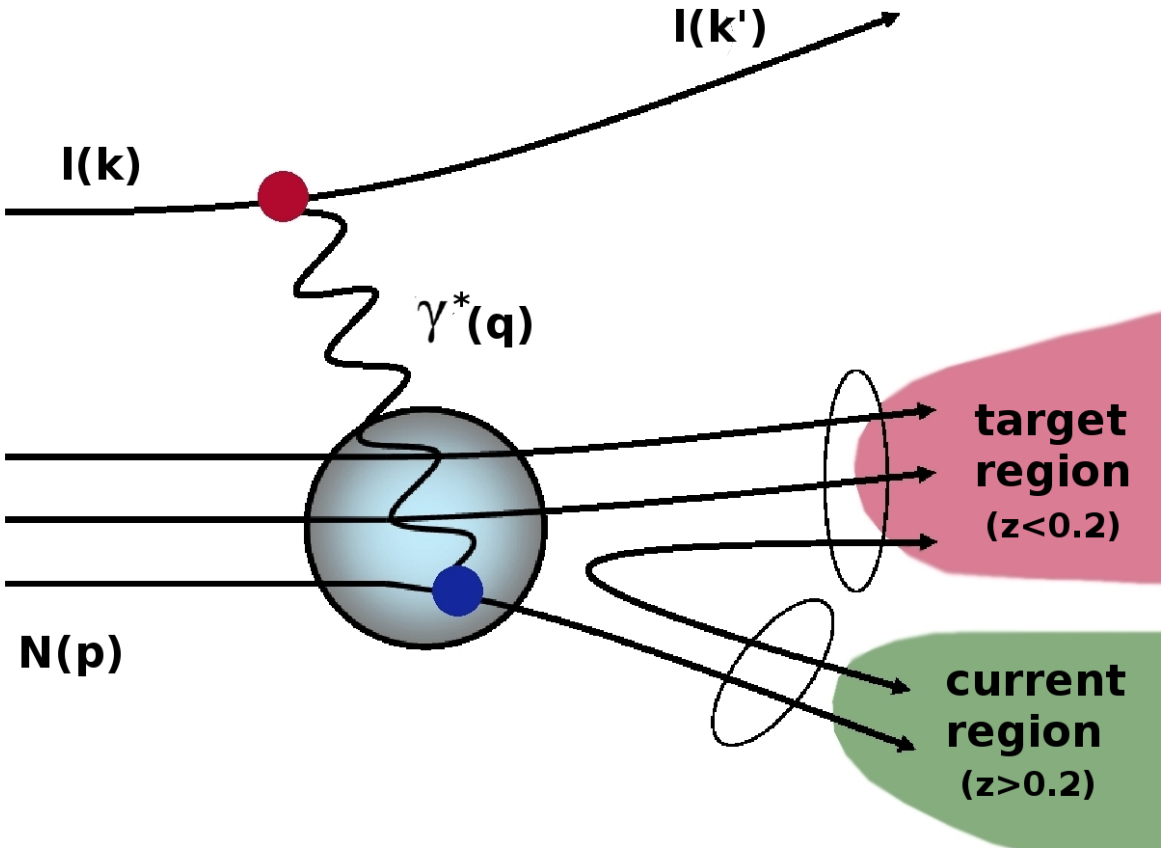
Contribution of quark flavour q:

$$\boxed{\Delta q = q\uparrow - q\downarrow}$$

$\Rightarrow$ Polarized **P**arton **D**istribution **F**unction (polarized PDF)

(q: *un*polarized PDF)

Deeply Inelastic Lepton-Nucleon Scattering



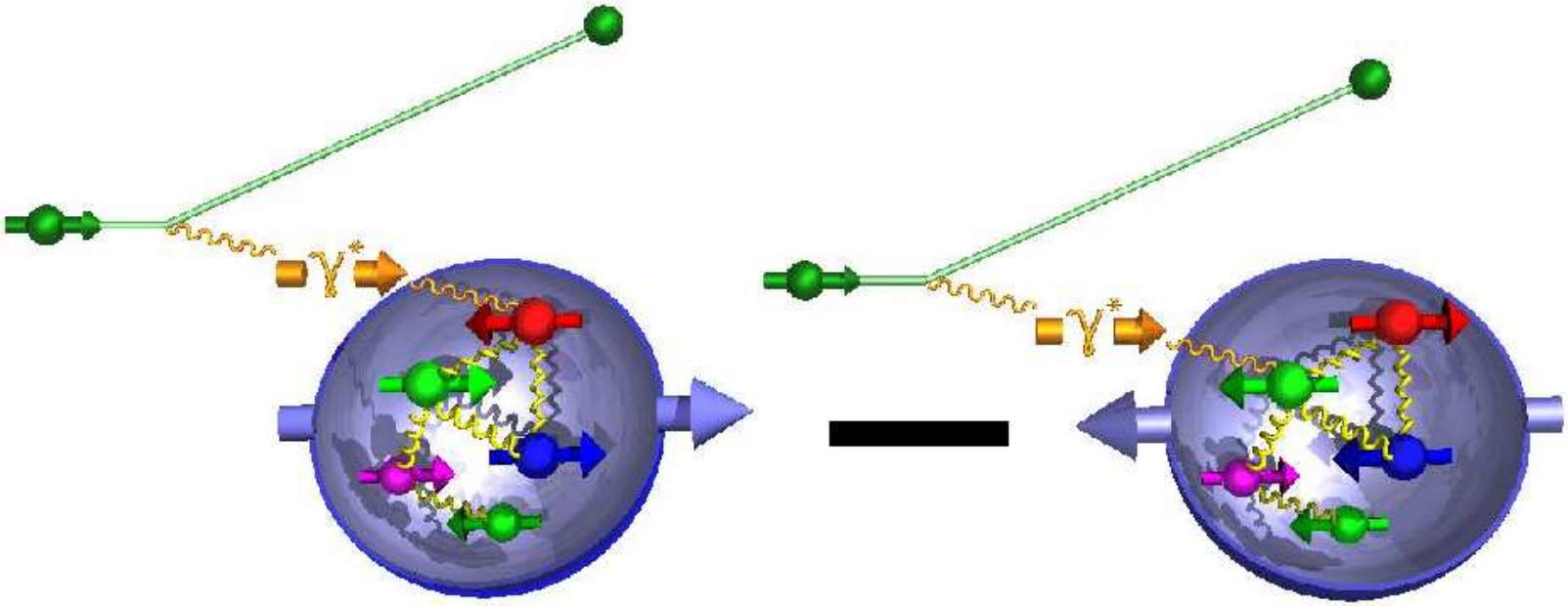
(lab frame)

$$
\begin{array}{rcl}
Q^2 & = & -q^2 \\
 & = & (k-k')^2 \\
\nu & = & E - E' \\
x & = & Q^2/2M\nu \\
\hline
z & = & E_h/\nu
\end{array}
$$

$$\sigma_h \sim \sum e_q^2 q(x) D_q^h(z)$$

(D_q^h: Fragmentation Function)

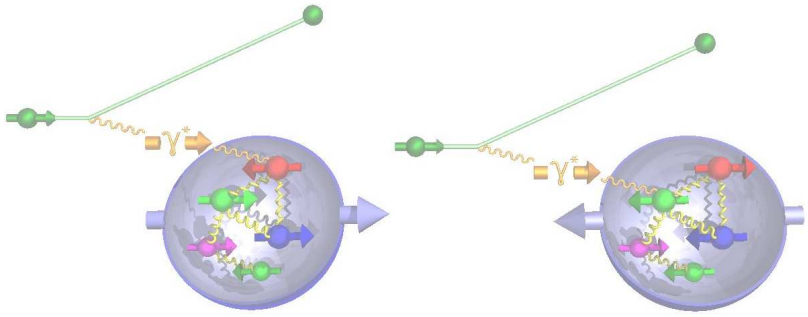
Asymmetries



$$A = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$

(counting rate N $\sim \sigma$, A $\sim A^{\gamma,N}, f, P_t, P_b, D_q^h$,
polarization $= \frac{\Delta q}{q}$)

Inclusive Asymmetry

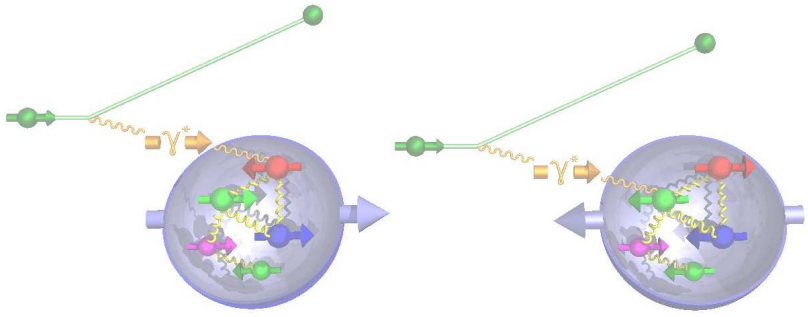


polarized PDF

$$A^{\gamma,N}(x) = \frac{\Sigma_q e_q^2}{\Sigma_q e_q^2 q(x)} \Delta q(x)$$

unpolarized PDF

Semi-Inclusive Asymmetry



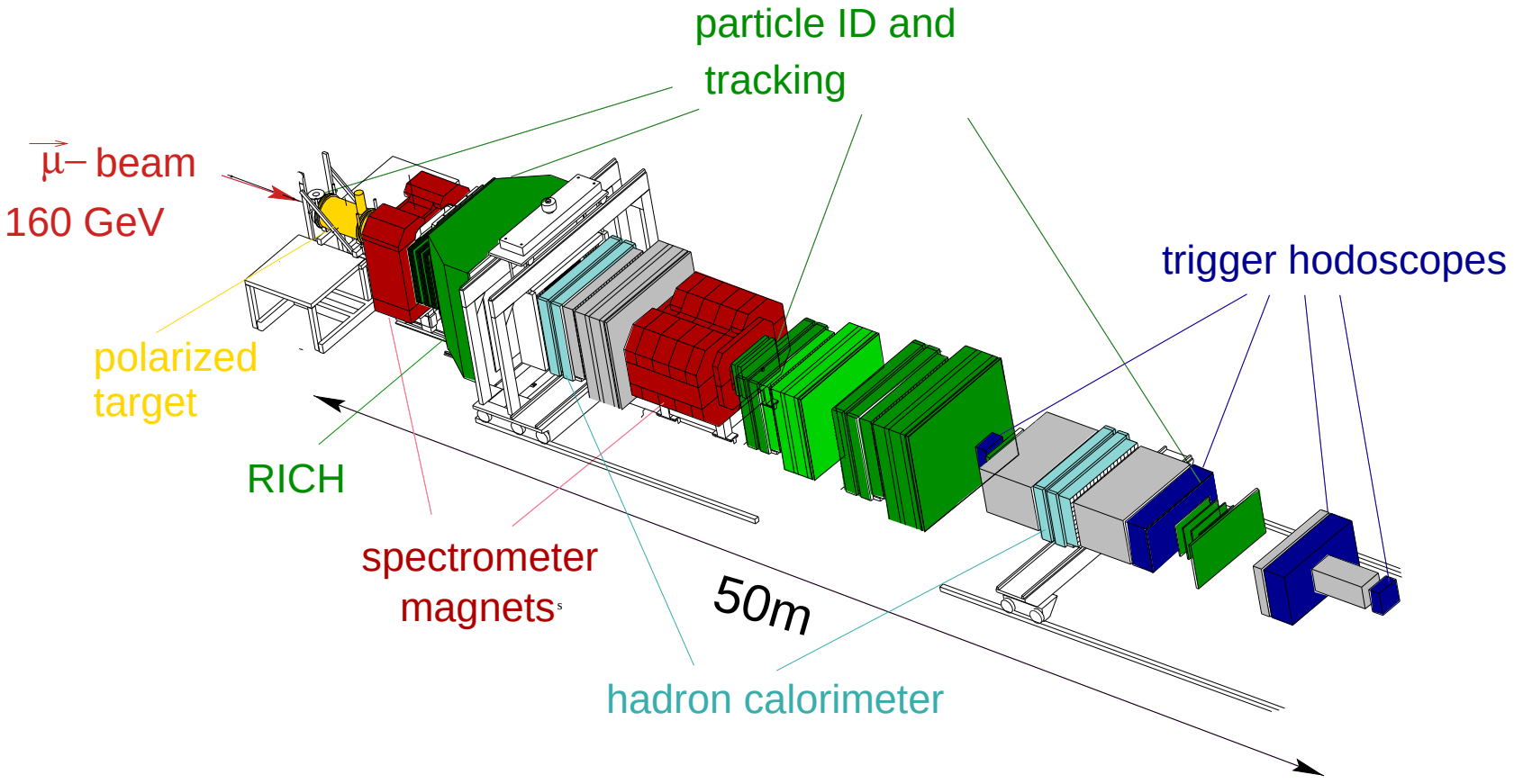
$$A^{\gamma,N}(x) = \frac{\Sigma_q e_q^2 D_q^h(z)}{\Sigma_q e_q^2 q(x) D_q^h(z)} \Delta q(x)$$

polarized PDF

unpolarized PDF

Fragmentation Function (FF)

The COMPASS Experiment

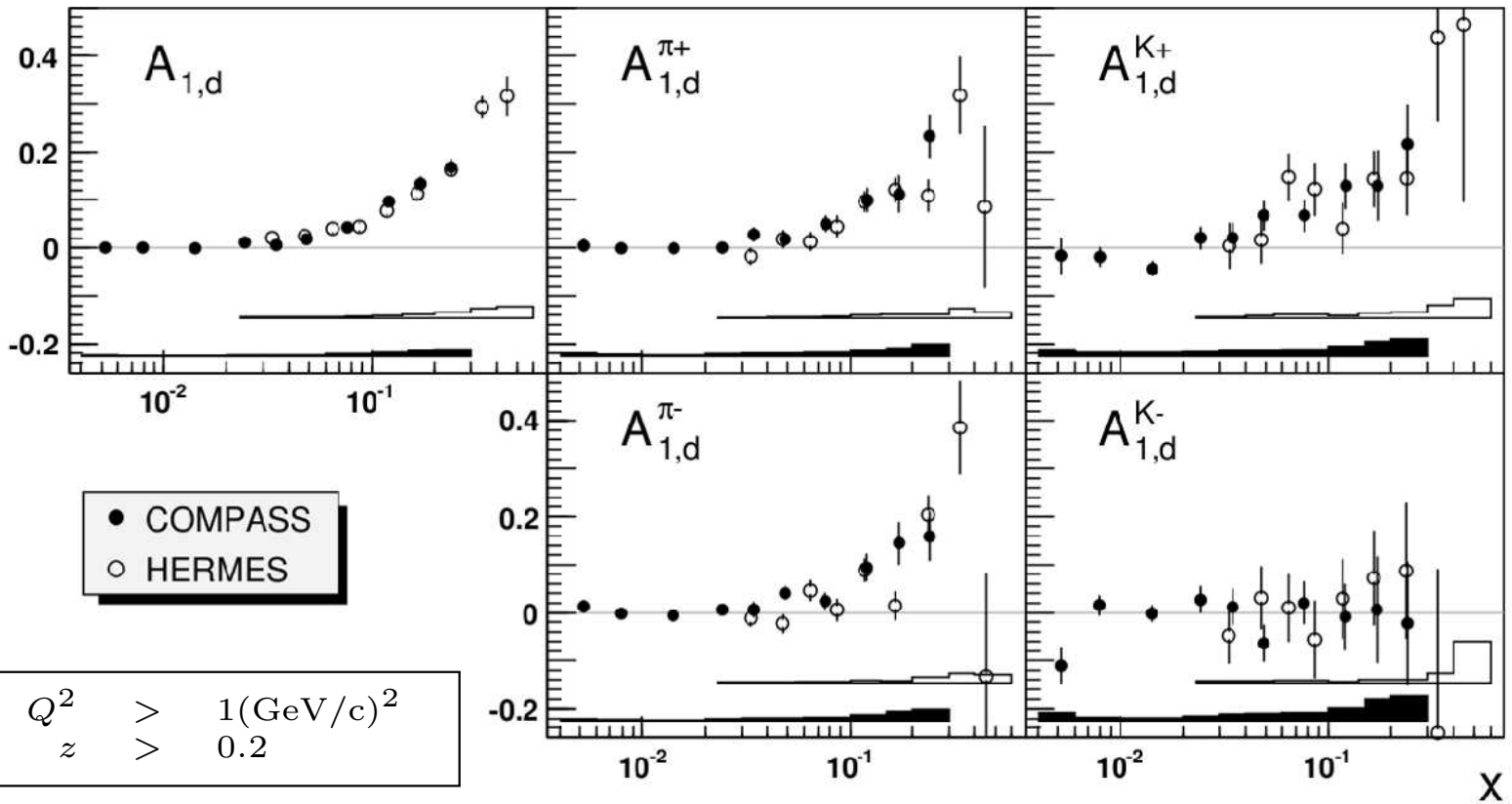


- μ^+ beam, $E = 160\,\mathrm{GeV}$, $P_B \approx 0.80$
- pol. target, ${}^6LiD$ (deuterons, $P_T \approx \pm 0.50$) / NH_3 (protons, $P_T \approx \pm 0.9$)
- tracking / particle ID / calorimetry

Asymmetries

inclusive *pion* *kaon*

deuteron



$Q^2 > 1(\mathrm{GeV/c})^2$
$z > 0.2$

Inclusive Asymmetry

$$A^{\gamma,N}(x) = \frac{\Sigma_q e_q^2 \Delta q(x)}{\Sigma_q e_q^2 q(x)}$$

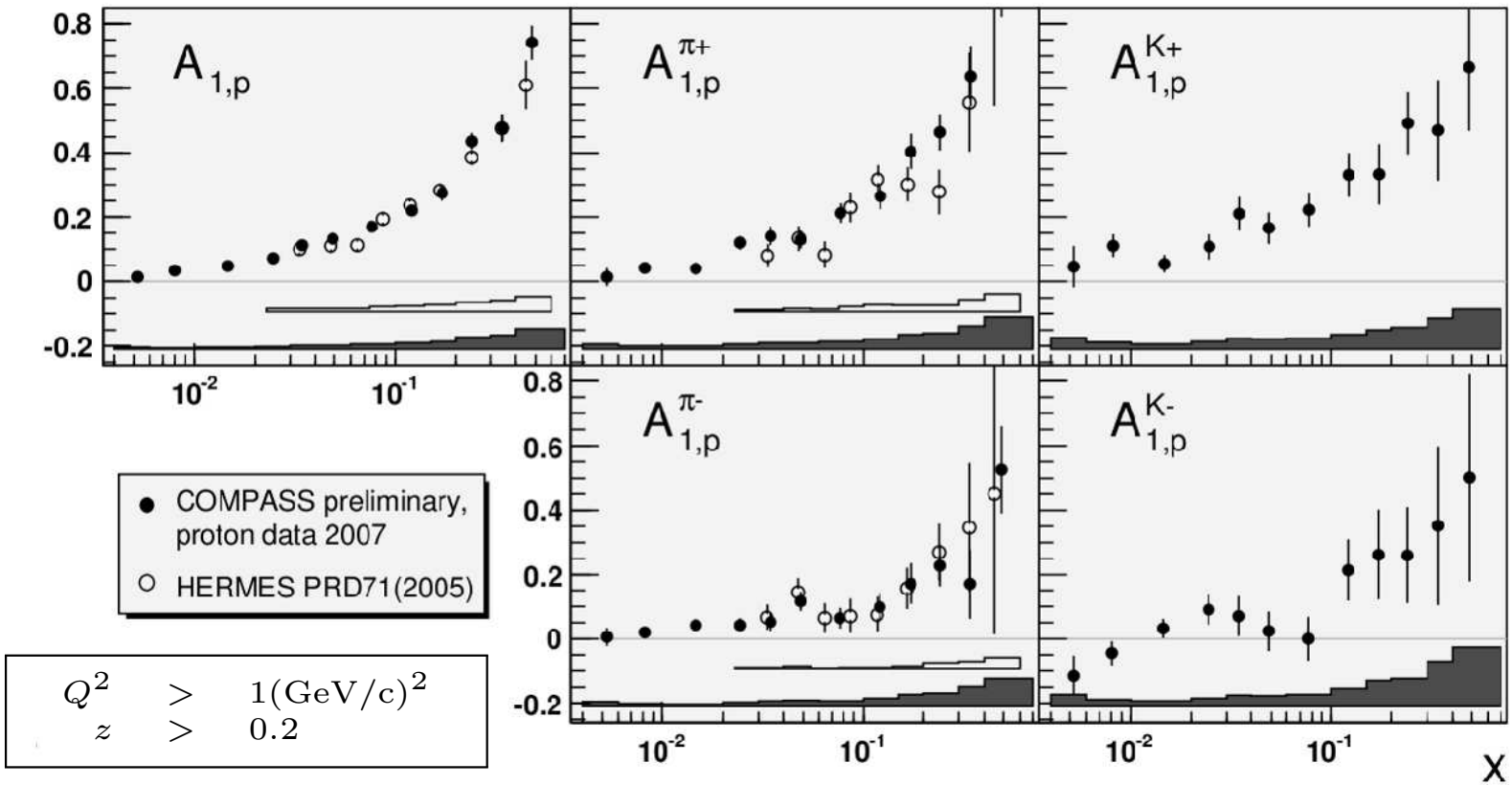
Semi-Inclusive Asymmetry

$$A_h^{\gamma,N}(x,z) = \frac{\Sigma_q e_q^2 \Delta q(x) D_q^h(z)}{\Sigma_q e_q^2 q(x) D_q^h(z)}$$

Asymmetries

inclusive *pion* *kaon*

proton



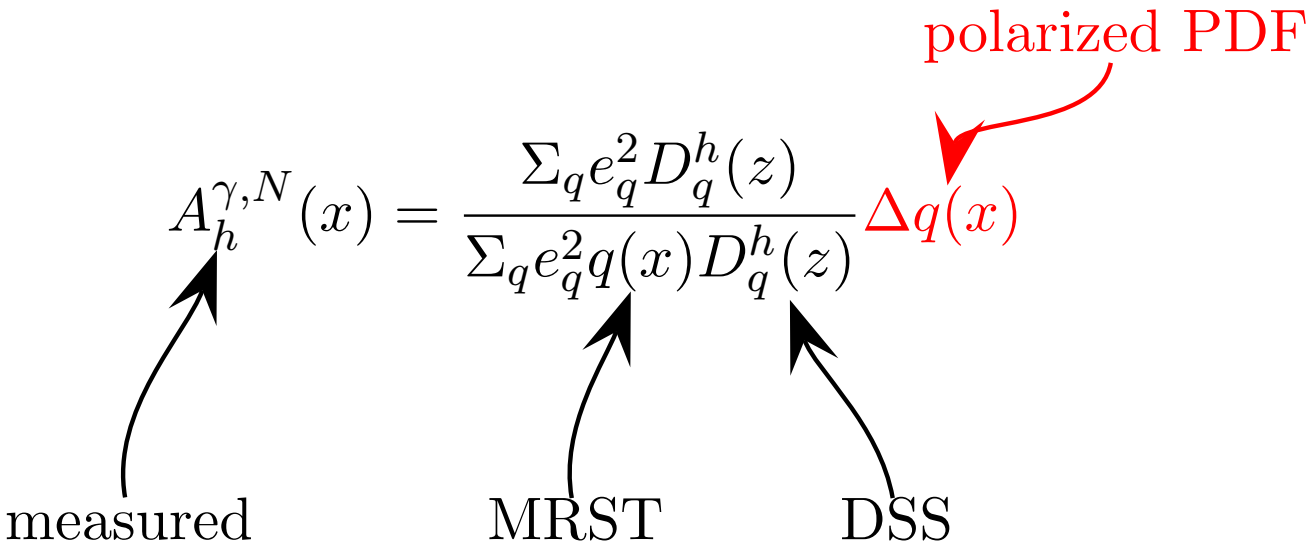
Inclusive Asymmetry

$$A^{\gamma,N}(x) = \frac{\Sigma_q e_q^2 \Delta q(x)}{\Sigma_q e_q^2 q(x)}$$

Semi-Inclusive Asymmetry

$$A_h^{\gamma,N}(x,z) = \frac{\Sigma_q e_q^2 \Delta q(x) D_q^h(z)}{\Sigma_q e_q^2 q(x) D_q^h(z)}$$

Polarized PDFs

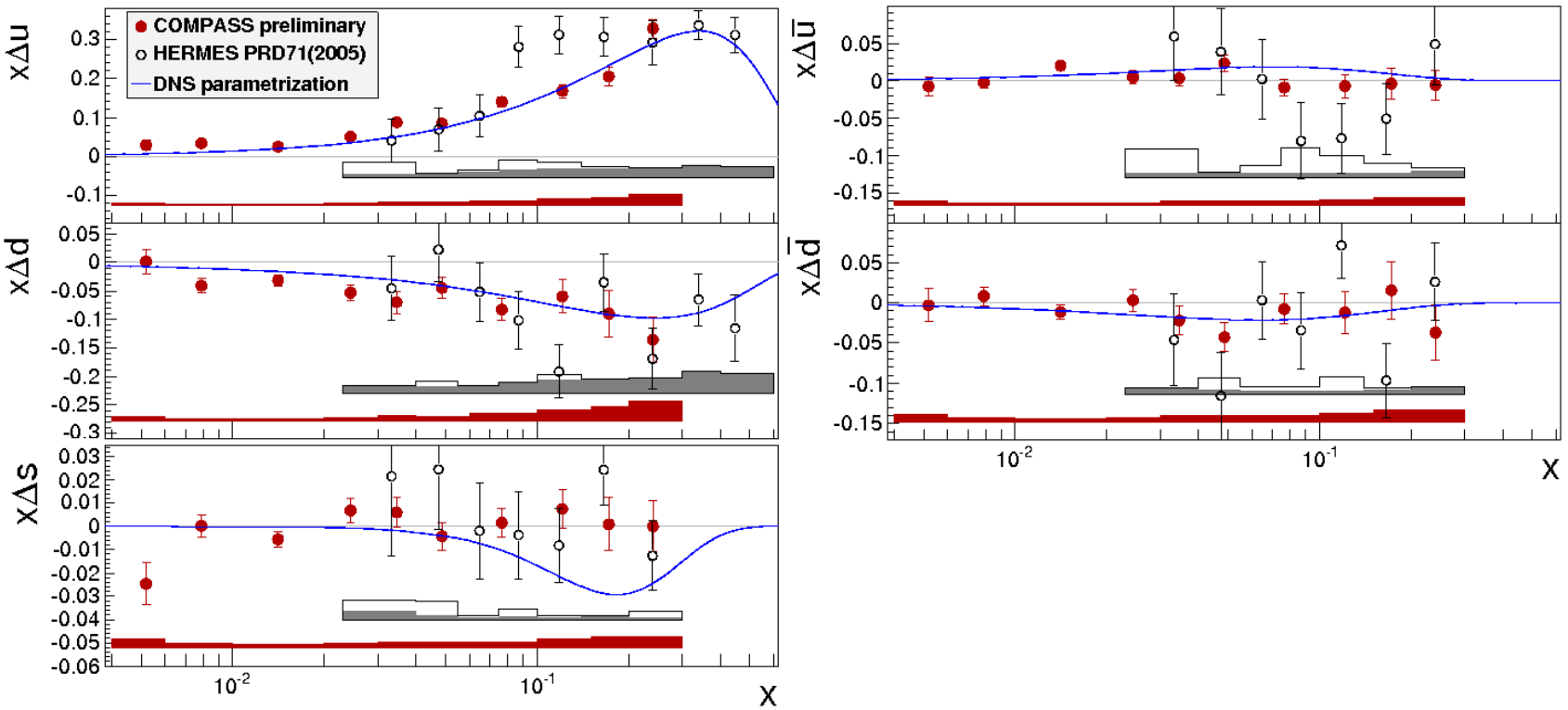


- MRST, DSS: recent analysis of world data

$h = \pi^+, \pi^-, K^+, K^-$, and inclusive; $N = p, d$

'MRST': Martin, Roberts, Sterling, Thorne; DSS: DeFlorian, Sassot. Stratmann

Polarized PDFs



- PDFs evaluated at $Q_0^2 = 3(\mathrm{GeV})^2$ in each x bin by least square fit
- x range expanded down to $x = 0.004$ in COMPASS analysis
  systematic and stat. errors reduced
- $x\Delta s$ compatible with zero / not in agreement with DNS parametrization

'DNS': Parametrization: DeFlorian, Navarro, Sassot

The Fragmentation Function Ratio R_{SF}

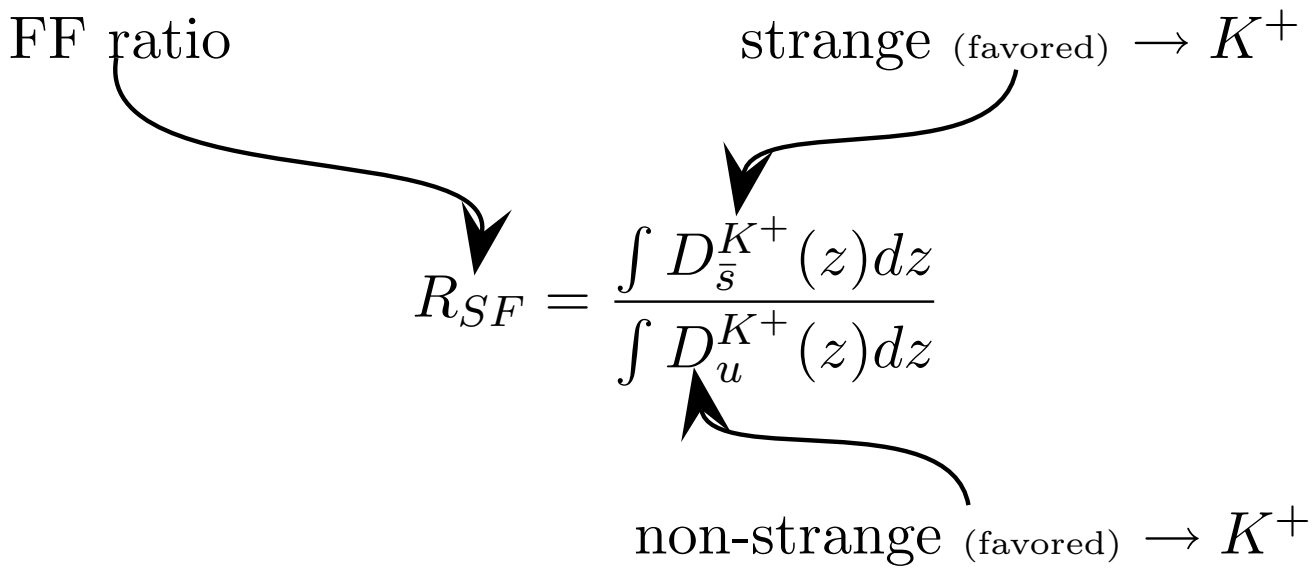
FF ratio

strange (favored) $\rightarrow K^+$

$$R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_{u}^{K^+}(z)dz}$$

non-strange (favored) $\rightarrow K^+$

The Fragmentation Function Ratio R_{SF}

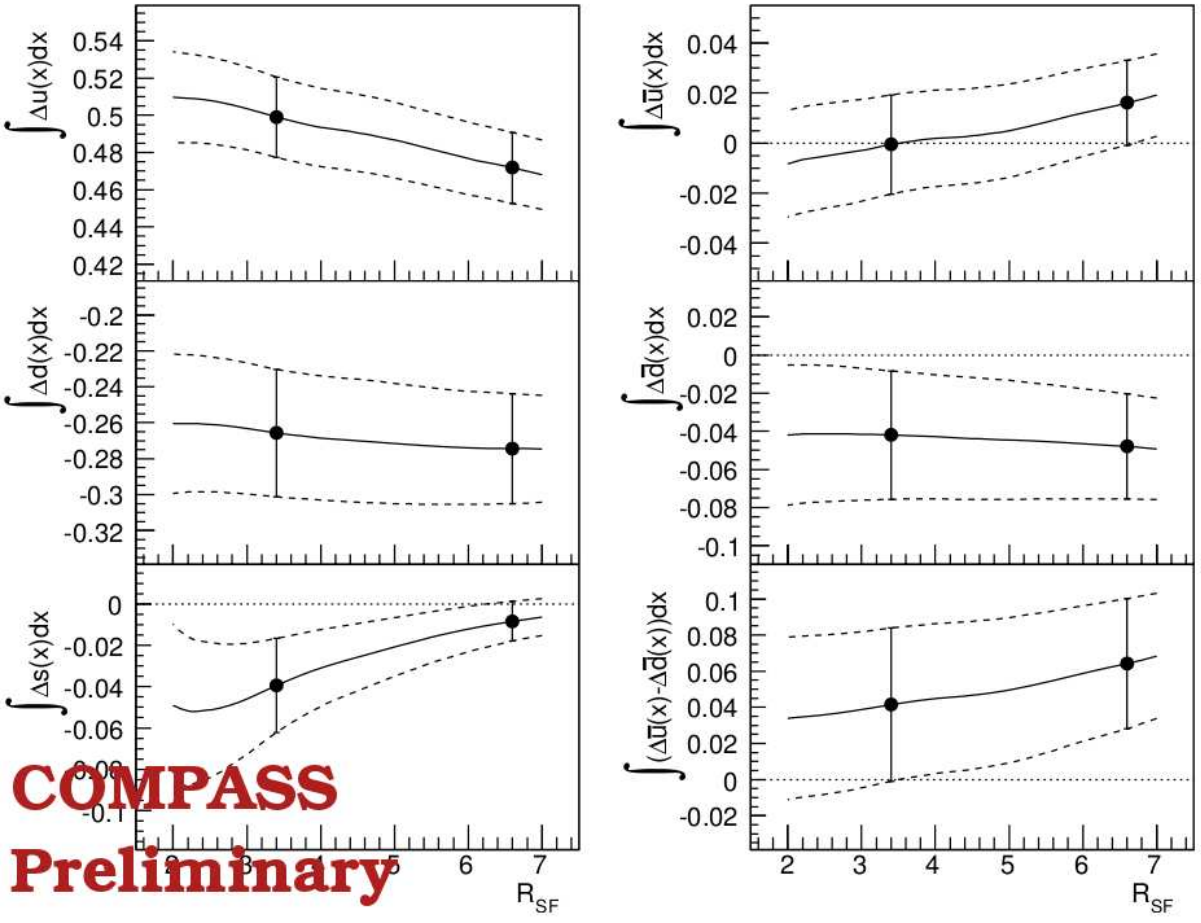


- main influence on Δs (via $A^{K^+ + K^-}$)
- very distinct values for different parametrizations

$R_{SF} \approx 6.6$ for DSS / 3.4 for EMC

'EMC': European Muon Collaboration, u quark fragmentation only $\Rightarrow D_{\bar{s}}^{K^+} = D_u^{\pi^+}$ assumed

First Moment Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$, Δs, $\Delta\bar{u} - \Delta\bar{d}$ vs. R_{SF}



$$R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_{u}^{K^+}(z)dz}$$

First moment of Δq: $\int_{0.004}^{0.3} \Delta q(x)dx$

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Hadron Multiplicities

Starting Point:

- Number of hadrons:

$$\frac{dN^h}{dxdz} \sim q(x), D(z)$$

- Normalized to the number of scattered leptons:

$$r^h = \frac{\frac{dN^h}{dxdz}}{\frac{dN^l}{dx}} = \frac{\sum_q e_q^2 q(x) D_q^h(z)}{\sum_q e_q^2 q(x)}$$

- Specify $h = K^+$ $(u\bar{s})$ and $h = K^-$ $(s\bar{u})$

  $\Rightarrow$ 12 Fragmentation Functions left

Reduction of the Fragmentation Functions

Charge conjugation invariance reduces the number of FFs:

$$D_s^{K^+} = D_{\bar{s}}^{K^-},\ D_u^{K^+} = D_{\bar{u}}^{K^-},\ \ldots$$

$\Rightarrow$ 6 FFs left

- largest $\rightarrow$ favored strange FF: $D_{\bar{s}}^{K^+}$
- followed by $\rightarrow$ favored up quark FF: $D_u^{K^+}$
- smallest $\rightarrow$ unfavored FFs assumed equal:

  $$D_s^{K^+} = D_d^{K^+} = D_{\bar{d}}^{K^+} = D_{\bar{u}}^{K^-} = \ldots$$

only 3 independent FFs left:

$D_{\bar{s}}^{K^+} = D_1$	$D_u^{K^+} = D_2$	$D_d^{K^+} = D_3$
("strange")	("favored")	("unfavored")

Isospin invariance does not reduce the FFs further: isospin parter of K^+: K^0

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Kaon Multiplicities

For deuteron target and $h = K^+, K^-$:

$$r^{K^+} = \frac{2\bar{s}\mathbf{D_1} + 4(u+d)\mathbf{D_2} + (u+d+5(\bar{u}+\bar{d})+2s)\mathbf{D_3}}{5(u+d+\bar{u}+\bar{d}+2(s+\bar{s}))}$$

$$r^{K^-} = \frac{2s\mathbf{D_1} + 4(\bar{u}+\bar{d})\mathbf{D_2} + (\bar{u}+\bar{d}+5(u+d)+2\bar{s})\mathbf{D_3}}{5(u+d+\bar{u}+\bar{d}+2(s+\bar{s}))}$$

(Note: $q(x)$ only dependent on x, $D(z)$ only dependent on z)

Fragmentation Function From Kaon Multiplicities: Method

Extraction of D_q^h by writing r^h in bins of x (fixed range of z):

$$\vec{r} \quad = \quad B(q) \quad \times \quad \vec{D}$$

$$\begin{pmatrix} r^{K^+}(x_1) \\ r^{K^-}(x_1) \\ r^{K^+}(x_2) \\ r^{K^-}(x_2) \\ r^{K^+}(x_3) \\ r^{K^-}(x_3) \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \\ b_{41} & b_{42} & b_{43} \\ b_{51} & b_{52} & b_{53} \\ b_{61} & b_{62} & b_{63} \end{pmatrix} \begin{pmatrix} D_1 \\ D_2 \\ D_3 \end{pmatrix}$$

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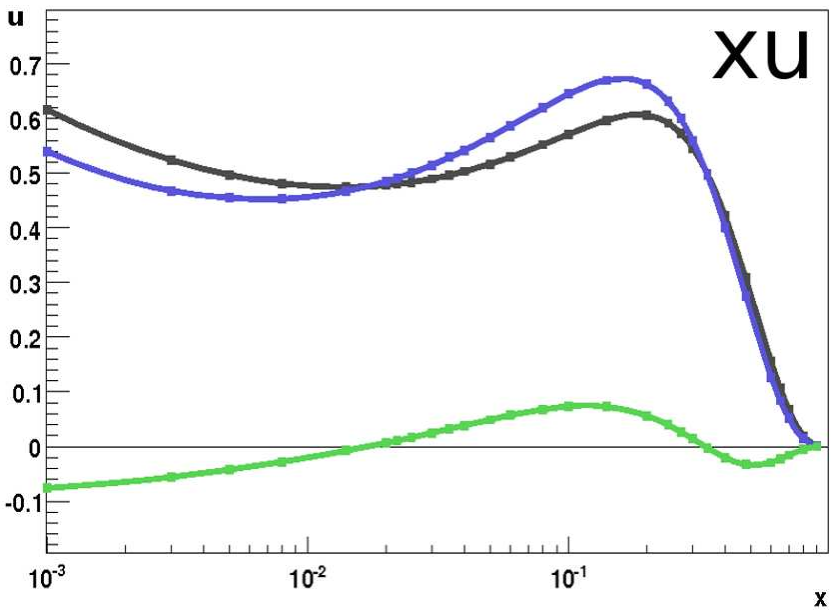
CTEQ6 & MSTW Parametrizations

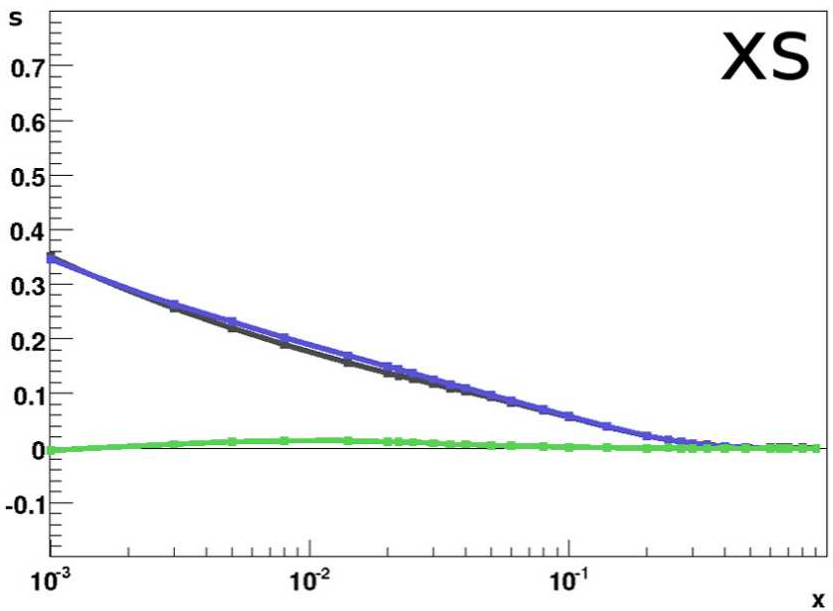
measured

CTEQ6, MSTW

$$\vec{r} = B(q) \times \vec{D}$$

FF





'CTEQ': The Coordinated Theoretical-Experimental Project on QCD

'MSTW': Martin-Stirling-Thorne-Watt Parton Distribution Functions; CTEQ - MSTW

Test and resulting FFs

- assumed $\vec{D}$ $(= D_1, D_2, D_3)$ $(= 0.3, 0.1, 0.03)$
- B from parametrization (CTEQ)
- $\Rightarrow \vec{r}$
- $\Rightarrow \vec{D}$

FF	CTEQ6	MSTW
D_1	0.300	0.260
D_2	0.100	0.102
D_3	0.030	0.030
R_{SF}	3.00	2.55

COMPASS statistics: $K^+ : 3.6 \times 10^6$, $K^- : 2.3 \times 10^6 \Rightarrow$ stat. error: $\leq 10^{-3}$

Summary & Outlook

- New extraction of Δq
- Large influence of fragmentation functions
- Method presented to extract $D_s^{K^+}$
  - COMPASS kaon statistic is sufficient
  - Systematic effects need to be investigated
- Next step: test the method with COMPASS kaon multiplicities
  $\Rightarrow$ detector acceptance / efficiencies need to be integrated