New COMPASS Results on Polarized Parton Distributions inside Nucleon

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on behalf of the COMPASS collaboration

- flavor separation
- $\Delta G/G$ measurements
  - open charm analysis
  - high-$p_T$ 2ihadrons, $Q^2 > 1 \,(\text{GeV/c})^2$ analysis
• **COLLABORATION**
  - about 210 physicists
  - 27 institutes

• **DETECTOR**
  - 60 m length
  - 2 (3) magnets
  - about 350 detector planes

• **POLARIZED TARGET**
  - $^6$LiD ($NH_3$) target
  - 2-3 cells (120 cm total length)
  - ± 50% (90%) polarization
  - polarization reversal every 8h-24h

• **POLARIZED BEAM**
  - positive muons at 160 GeV/c
  - polarization ≈80%

• **FEATURES**
  - acceptance: 70 → 130 mrad (2006)
  - track reconstruction: $p > 0.5$ GeV/c
  - identification: $\pi$, $K$, $p$ (RICH) above 2, 9, 18 GeV/c respectively
Semi-Inclusive Asymmetries and Flavour Separation
Semi-Inclusive Asymmetries

- semi-inclusive asymmetries were measured on both $p$ and $d$ targets
- for the first time Kaon asymmetries were measured on $p$ target
- in the LO approximation 
  \[ A^h_1(x, Q^2, z) = \frac{\sum_q e_q^2 \Delta q(x, Q^2) D^h_q(z, Q^2)}{\sum_q e_q^2 q(x, Q^2)} \]
- $D^h_q$ are fragmentation Functions (FF) of quark $q$ into hadron $h$
- with 10 asymmetries ($A^{incl}_{1p,d}, A^{\pi\pm}_{1p,d}, A^{K\pm}_{1p,d}$) and 5 unknown parameters ($\Delta u, \Delta d, \Delta \bar{u}, \Delta \bar{d}, \Delta s$) a flavor separation is possible
LO Flavour Separation

- results are published in PLB 693 (2010) 227
- good agreement between COMPASS data and DSSV parametrization
Strange Sea Polarization

• \( \int_0^1 \Delta s(x) + \Delta \bar{s}(x) \, dx = 2\Delta S \) is negative from inclusive asymmetries
  \( 2\Delta S = -0.09 \pm 0.01 \pm 0.02 \)

• \( \Delta S \) obtained in semi-inclusive analysis strongly depends upon the choice of fragmentation functions used

• ratio \( D_s^K / D_u^K = D_s^{K^+} / D_u^{K^+} \), known as \( R_{SF} \) is especially important

• try to extract \( R_{SF} \) from COMPASS data alone cf. Nour Makke talk on hadron multiplicities

![Graph showing \( \Delta S \) vs. \( R_{SF} \)]
\( \Delta G/G \) from Open Charm Analysis
2002-2007 Data
ΔG/G from Open Charm Analysis

- open-charm - clean source of PGF
- hard scale \( \approx 4m_c^2 \), even though \( Q^2 < 1\) (GeV/c)²
- low statistics - various decay modes of D mesons analyzed

- Number of \( D^0 \) events : 65500
- Number of \( D^* \) 29000 (13100 in the golden channel, \( D^* \rightarrow K\pi\pi_{soft} \) )
Gluon Polarization

\[
\frac{\Delta G}{G} = \frac{1}{P_tP_bf_aLLS_{S+B}} A_{\mu N}^{raw}
\]

- \( P_t, P_b, f \) - target, beam polarizations and dilution factor
- analyzing power, \( a_{LL} \), is taken from MC
- \( \frac{S}{S+B} \) is parametrized on data using a Neural Network approach
- NOTE: In reality a more complex \( \Delta G/G \) extraction method is used:
  - in the analysis we use weight \( P_bf_aLLS_{S+B} \) on the event by event basis to improve the statistical accuracy of the measurement.
  - \( A_{bgr} = \frac{1}{P_tP_bfDA_{\mu N}^{raw}} \) is extracted simultaneously with \( \Delta G/G \),
The $\Delta G/G$ Results

$\Delta G/G = -0.08 \pm 0.21 \pm 0.11$

$< x_G > = 0.11^{+0.11}_{-0.05} < \mu^2 > = 13 \text{ (GeV/c)}^2$

<table>
<thead>
<tr>
<th>channel</th>
<th>$\Delta G/G$</th>
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<tbody>
<tr>
<td>$D^* \rightarrow K\pi\pi_{slow}$</td>
<td>$-0.19 \pm 0.30$</td>
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<tr>
<td>$D^0 \rightarrow K\pi$</td>
<td>$0.02 \pm 0.42$</td>
</tr>
<tr>
<td>$D^* \rightarrow K\pi\pi^0\pi_{slow}$</td>
<td>$-0.41 \pm 0.58$</td>
</tr>
<tr>
<td>$D^* \rightarrow K3\pi\pi_{slow}$</td>
<td>$0.63 \pm 0.83$</td>
</tr>
<tr>
<td>$D^* \rightarrow K_{subth}\pi\pi_{slow}$</td>
<td>$0.5 \pm 0.1$</td>
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- large part of the systematic error is proportional $\delta \Delta G/G_{stat}$
- key point: $\sigma_{stat} >> \sigma_{sys}$
NLO Analysis of Open Charm Events

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  
(g)  
(h)  
(i)  
(j)  
(k)  
(l)  
(m)  
(n)  
(o)
NLO Analysis of Open Charm Events cont.

- AROMA generator is used with parton showers ON
- on the event by event basis parton shower simulates the phase-space for NLO calculation
- in NLO part of the $D^0$'s are not produced from PGF processes $\rightarrow A_{corr} \sim A_{1}^{d,p}$ term appears.
- significant differences are observed between $a_{LL}^{LO}$ and $a_{LL}^{NLO}$ as well as between $x_{G}^{LO}$ and $x_{G}^{NLO}$

![Graph 1](image1.png)

![Graph 2](image2.png)
Results of NLO $\Delta G/G$ Extraction

- $\Delta G/G = \frac{A^{\gamma N} - A_{corr}}{\langle a^A_{DSSV} / D \rangle}$
- the preliminary result is $\Delta G/G_{NLO} = -0.20 \pm 0.21 \pm 0.08$
- $\mu^2 = 13 \text{ (GeV/c)}^2$, $< x_{G,NLO} > = 0.28$
- publication of the $\Delta G/G$ results obtained in LO and NLO is being prepared
Properties of $D^*$ Mesons

- COMPASS also studies unpolarized $D^*$ production

- observed production cross section for $D^{*\pm}$ mesons is $\sigma = 1.8 \pm 0.4\text{nb}$, to be compared with 2.6 nb from the AROMA generator.

- this cross section is for $D^*$ mesons with laboratory energies between 22 and 86 GeV seen by the COMPASS experiment,

- differential cross sections have been measured:
  - they are compared with EMC results (green)
  - shape is compared with AROMA predictions
Properties of $D^*$ Mesons cont.

• non zero asymmetries are observed between $D^{*+}$ and $D^{*-}$ production,

• this result may suggest that other processes than PGF are also involved in the $D^*$ production

• separate publication is in progress
High-$\rho_T$ Hadron Pairs Analysis
2002-2006 Data

hep-ex/1202.4064, submitted to PLB
High-$p_T$ Hadron Pairs Analysis
2002-2006 Data, $Q^2 > 1$ (GeV/c)$^2$

- much larger statistics than in the open charm analysis (c.a. 7.3M)
- in LO three processes are contributing: LP, PGF and QCDC
- the fraction of each process has to be estimated from MC
- in general, for higher $p_T$ a larger fraction of PGF is expected
- perturbative scale is defined by $Q^2 > 1$ (GeV$^2$),
- as the scale is defined by $Q^2$, the cuts on $p_T$ of hadrons can be kept low: $p_{T1} > 0.7$ (GeV/c) and $p_{T2} > 0.4$ (GeV/c)
MC and Data Comparison

- LEPTO generator is used in the analysis
- parton Shower is ON, PDF set it MSTW08LO
- to improve data/MC agreement $k_T$ and fragmentation parameters were adjusted, hadron variables affected
The Extraction of $\Delta G/G$

- observed asymmetry in the 2 hadrons sample is:

$$A_{2h}^{LL}(x_{Bj}) = R_{PGF} a_{LL}^{PGF} \frac{\Delta G}{G}(x_G) + R_{LP} D A_{1}^{LO}(x_{Bj}) + R_{QCDC} a_{LL}^{QCDC} A_{1}^{LO}(x_{C})$$

$$- A_{1}^{LO} = \frac{\sum_{i} e_{i}^{2} \Delta q_{i}}{\sum_{i} e_{i}^{2} q_{i}}$$

- $Rs$ - fractions of the sub-processes (LO, PGF, QCDC), taken from MC

- $a_{LL}s$ - analyzing powers for LO, PGF and QCDC, taken from MC

- we have two unknowns $A_{1}^{LO}$ and $\Delta G/G$, and so far only one equation...

- additional information is provided by the inclusive sample:

$$A_{1}^{d}(x_{Bj}) = R_{PGF}^{incl} a_{LL}^{incl,PGF} \frac{\Delta G}{G}(x_G) + R_{LP}^{incl} D A_{1}^{LO}(x_{Bj}) + R_{QCDC}^{incl} a_{LL}^{incl,QCDC} A_{1}^{LO}(x_{C})$$

- $\Delta G/G = \frac{A_{2h}^{LL}(x_{Bj}) + A_{corr}}{\beta}$

- $\beta = a_{PGF}^{LL} R_{PGF} - a_{PGF, incl}^{LL} R_{PGF}(\frac{R_{L}^{incl}}{R_{L}^{incl}} + \frac{R_{C}^{incl}}{R_{L}^{incl}} a_{LL}^{C})$

- $A_{corr}$ is a linear function of $A_{1}^{d}(x_{Bj} \sim 0.03)$ and $A_{1}^{d}(x_{C} \sim 0.11)$
The Extraction of $\Delta G/G$ cont.

- to reduce statistical error we use a weighted method for the asymmetry extraction. We must know all $R_s$ and $a_{LL}s$ on the event by event basis
- we use a Neural Network trained on MC to obtain parametrizations which are used on data, *cf.* example below
Results

• $\Delta G/G = 0.125 \pm 0.060 \pm 0.063$

• $\langle x_G \rangle = 0.09$, $\mu^2 = 3 \text{ (GeV/c)}^2$

• the dominating systematic contribution comes from the MC (0.045)

• COMPASS obtained results in 3 bins of $x_G$
  - we use a Neural Network to parametrize $x_{G,true}$
  - the correlation between $x_{G,\text{param}}$ and $x_{G,true}$ is about 60%

<table>
<thead>
<tr>
<th>$\langle x_G \rangle$</th>
<th>$\Delta G/G$</th>
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<tr>
<td>$0.07^{+0.05}_{-0.03}$</td>
<td>$0.147 \pm 0.091 \pm 0.088$</td>
</tr>
<tr>
<td>$0.10^{+0.07}_{-0.04}$</td>
<td>$0.079 \pm 0.096 \pm 0.081$</td>
</tr>
<tr>
<td>$0.17^{+0.10}_{-0.06}$</td>
<td>$0.185 \pm 0.165 \pm 0.143$</td>
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Summary of $\Delta G/G$ from COMPASS

- all results agree with each other
- the $\Delta G$ is small, but the data are not precise enough to determine its sign
Summary

• LO flavour separation results were shown
  – the results agree with DSSV NLO parametrization
  – COMPASS is on the way to extract FF ratios, which are needed to understand better $\Delta S$ puzzle
  – if $R_{SF}$ is small then inclusive and semi-inclusive results for $\Delta S$ agree with each other

• updated results for $\Delta G/G$ obtained in various analyses were presented
  – updated high-$p_T$ hadron pairs, $Q^2 > 1$ (GeV/c)$^2$ analysis: $\Delta G/G = 0.125 \pm 0.060 \pm 0.063$, subm. to PLB
  – updated LO open charm analysis: $\Delta G/G = -0.08 \pm 0.21 \pm 0.11$
  – new NLO open charm analysis: $\Delta G/G = -0.20 \pm 0.21 \pm 0.08$
  – all world results agree with each other
  – $\Delta G$ is small, but the sign of it is still not determined