New results on quark helicity distributions and gluon polarization from the COMPASS experiment at CERN

Krzysztof Kurek SINS, Warsaw



16-22 July, Krakow, Poland

European Physical Society

ELEP 2

Beam: $2 \cdot 10^8 \ \mu^+$ spill (4.8s / 16.2s)Luminosity ~5 $\cdot 10^{32} \ cm^{-2} \ s^{-1}$ Beam polarization: -80%Beam momentum: 160 GeV/cTarget polarization: P_T = 50%, f ~ 40 %for ⁶LiD (2002 - 2006)

LHC

COMPASS

COMPASS Collaboration at CERN

Common Muon and Proton Apparatus

for Structure and Spectroscopy

Czech Rep., France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia and CERN

Bielefeld, Bochum, Bonn, Burdwan and Calcutta, CERN, Dubna, Erlangen, Freiburg, Lisbon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw, Yamagata

~240 physicists, 30 institutes







Krzysztof Kurek

gluon polarization from COMPASS

Contents

- Introduction
- New results on quark helicity distributions
- Gluon polarization from high-p_T hadron pairs
- New result on gluon polarization from open-charm measurement
- Summary



Polarized Deep Inelastic scattering



Inclusive asymmetry:

 $A_{1}(x,Q^{2}) = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow}} \approx \frac{\sum_{q} e_{q}^{2} \Delta q(x,Q^{2})}{\sum_{q} e_{q}^{2} q(x,Q^{2})} = \frac{g_{1}(x,Q^{2})}{F_{1}(x,Q^{2})}$ $A_{1}^{h}(x,z,Q^{2}) = \frac{\sigma_{\uparrow\downarrow}^{h} - \sigma_{\uparrow\uparrow}^{h}}{\sigma_{\uparrow\downarrow}^{h} + \sigma_{\uparrow\uparrow}^{h}} \approx \frac{\sum_{q} e_{q}^{2} \Delta q(x,Q^{2}) D_{q}^{h}(z,Q^{2})}{\sum_{q} e_{q}^{2} q(x,Q^{2}) D_{q}^{h}(z,Q^{2})}$ semi-nclusive asymmetry:

3 years of deuteron data taking in COMPASS: years 2002-2004 : $89*10^6$ events for Q² >1 (GeV/c)²

Phys.Lett.B 647 (2007)8

First moment of g1

Compass only

$$\Gamma_1^N(Q^2) = \frac{1}{9} \left(1 - \frac{\alpha_s(Q^2)}{\pi} + O(\alpha_s^2) \right) \left(a_0(Q^2) + \frac{1}{4}a_8 \right)$$

Phys.Lett.B 647 (2007)8

from Y. Goto *et al.*, PRD62 (2000) 034017: (SU(3)_f assumed for weak decays) $a_8 = 0.585 \pm 0.025$

$$a_{0|Q_0^2 = 3(GeV/c)^2} = 0.35 \pm 0.03(stat) \pm 0.05(syst)$$
 QCD NLO

$$a_{0|Q^2 \to \infty} = 0.33 \pm 0.03(stat) \pm 0.05(syst)$$
 beyond NLO

$$(\Delta s + \Delta \overline{s}) = \frac{1}{3}(\hat{a}_0 - a_8) = -0.08 \pm 0.01(stat) \pm 0.02(syst)$$

EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek New results on quark helicity distributions and gluon polarization from COMPASS



Difference asymmetries

Idea: Phys.Lett.B230(1989)141, SMC:Phys.Lett.B369(1996)93, COMPASS: Phys.Lett.B660(2008)458

$$A^{+-} = \frac{(\sigma_{\uparrow\downarrow}^{h^+} - \sigma_{\uparrow\downarrow}^{h^-}) - (\sigma_{\uparrow\uparrow}^{h^+} - \sigma_{\uparrow\uparrow}^{h^-})}{(\sigma_{\uparrow\downarrow}^{h^+} - \sigma_{\uparrow\downarrow}^{h^-}) + (\sigma_{\uparrow\uparrow}^{h^+} - \sigma_{\uparrow\uparrow}^{h^-})}$$

$$A_d^{\pi^+ - \pi^-}(x) = A_d^{K^+ - K^-}(x) = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$

Only valence quarks!

Fragmentation functions cancell out in LO and under the assuption of independent fragmentation.



♦QCD evolution $g_1(x,Q^2) = \frac{1}{2} \langle e^2 \rangle [C_q^s \otimes \Delta \Sigma + C_q^{NS} \otimes \Delta q^{NS} + 2n_f C_G \otimes \Delta G]$

Semi-inclusive asymmetries compared to theory predictions based on gluon polarization "model" (method used in RHIC)

"Direct" measurement: idea - tag photon-gluon fusion (PGF) process

- Observation of the two hadrons with high-p_T
- Observation of the charmed mesons produced via open-charm mechanism

high-p_⊤ hadron pairs

R.D.Carlitz, J.C.Collins and A.H.Mueller, Phys.Lett.B 214, 229 (1988) Revisited by A.Bravar, D.von Harrach and A.Kotzinian, Phys.Lett.B 421, 349 (1998) Applied by SMC, HERMES and COMPASS



The simple idea: three basic processes, PGF probes gluons

Large statistics but Monte Carlo dependent analysis, limited to LO

Two kinematical regions:

• small Q² - Q²<1 (GeV/c)² - here p_T is a perturbative scale, also resolved photon contribution important (~50%) - COMPASS 2002-2003 data PLB **633** (2006) 25-32 • large Q² - Q²>1 (GeV/c)² - scale Q² - 2002-2004 data, new method based on Neural Network approach used - this talk



Open-charm analysis



- Huge combinatorial background
- NLO corrections potentially important



$$A^{raw} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} = P_B P_T f a_{LL} \frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}} \frac{\Delta g}{g} + A^{bgd}$$

 P_B , P_T - are beam and target polarizations,

f - dilution factor (~0.4 for ⁶LiD target)

 a_{LL} is a partonic asymmetry (analysing power) for subprocess: $\mu g \rightarrow cc_{bar} \mu$

- $\frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}}$ is parameterized in terms of 10 variables, not just as a function of the reconstructed mass.
- each event is weighted with its analyzing power:

f P_B a_{LL}
$$\frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}}$$

Large gain in statistics (a_{LL} has positive and negative values)

- events are simultaneously weighted with $(\dots \frac{\sigma_{BGD}}{\sigma_{PGF} + \sigma_{bgd}})$ \Rightarrow allows simultaneous extraction of signal and background asymmetries,
 - more efficient than side band subtraction

Helicity distributions



EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek New results on quark helicity distributions and gluon polarization from COMPASS



New: Proton data 2007, g1



New: Proton data 2007



QCD NLO fit allows estimate first moment and test Bjorken sum rule:

$$\Gamma_1^{NS}(Q^2) = \frac{1}{6} \frac{g_A}{g_V} C_1^{NS}(Q^2) \qquad g_A/g_V = 1.29 \pm 0.05 \text{(stat.)}$$

 $C^{NS} = 0.89 Q^2 = 3 (GeV/c)^2$

Δs from charged Kaon's asymmetry



$$\frac{\Delta s}{s} = \mathbf{A}_1^{d} + \left(\mathbf{A}_1^{K^+ + K^-} - \mathbf{A}_1^{d}\right) \frac{\mathbf{Q}/s + \alpha}{\alpha - 0.8}$$

$$\alpha = \frac{2R_{UF} + 2R_{SF}}{3R_{UF} + 2} \qquad \mathbf{Q} = \mathbf{u} + \overline{\mathbf{u}} + \mathbf{d} + \overline{\mathbf{d}}$$

$$\mathbf{R}_{\mathsf{UF}} = \frac{\int \mathbf{D}_{\mathsf{d}}^{\mathsf{K}^{+}}(\mathbf{z}) d\mathbf{z}}{\int \mathbf{D}_{\mathsf{u}}^{\mathsf{K}^{+}}(\mathbf{z}) d\mathbf{z}} \qquad \mathbf{R}_{\mathsf{SF}} = \frac{\int \mathbf{D}_{\overline{\mathsf{s}}}^{\mathsf{K}^{+}}(\mathbf{z}) d\mathbf{z}}{\int \mathbf{D}_{\mathsf{u}}^{\mathsf{K}^{+}}(\mathbf{z}) d\mathbf{z}}$$

if $A_1^d = A^{K^+ + K^-} \implies \Delta s \ge 0$, insensitive to FFs if $A^{K^+ + K^-} < 0$ (at low x) $\implies \Delta s < 0$

New results on quark helicity distributions and gluon polarization from COMPASS

COMPAS:



- \bullet RUF fixed at 0.14 from the DSS fragmentation functions
- Large statistical uncertainty due to R_{SF}, slight dependence on R_{UF}
- If $R_{SF}>5 \Delta s(SIDIS)>\Delta s(DIS)$ and $\Delta s < 0$ for x<0.004
- •If R_{SF} <4: A^{K} becomes insensitive to Δs

 Δs (inclusive) = -0.045 ± 0.005 ± 0.010

in LO pQCD

 Δs (SIDIS) = -0.01 ± 0.01 ± 0.01



New: Proton data 2007, flavour separation



$\Delta G/G$ from high-p_T hadron pairs



EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek New results on quark helicity distributions and gluon polarization from COMPASS



$$\begin{split} \frac{\Delta G}{G}(x_{G}) &= \frac{A_{LL}^{2h}(x_{Bj}) + A^{corr}}{\beta} \\ \beta &= \left[a_{LL}^{PGF} R_{PGF} - a_{LL}^{PGF,incl} R_{PGF}^{incl} \left(\frac{R_{L}}{R_{L}^{incl}} + \frac{R_{C}}{R_{L}^{incl}} \frac{a_{LL}^{C}}{D} \right) \right] \\ A^{corr} &= -A_{1}(x_{Bj}) D \frac{R_{L}}{R_{L}^{incl}} - A_{1}(x_{C}) \beta_{1} + A_{1}(x_{C}') \beta_{2} \\ \beta_{1} &= \frac{1}{R_{L}^{incl}} \left(a_{LL}^{C} R_{C} - a_{LL}^{C,incl} R_{C}^{incl} \frac{R_{L}}{R_{L}^{incl}} \right) \qquad \beta_{2} = a_{LL}^{C,incl} \frac{R_{C} R_{C}^{incl}}{(R_{L}^{incl})^{2}} \frac{a_{LL}^{C}}{D} \end{split}$$

R's are fractions of the sub-processes (LO,PGF, QCDC) in high- p_T and inclusive samples, respectively a_{LL} 's are so-called analysing powers for LO,PGF and QCDC (the ratio of partonic polarised and unpolarised cross sections for sub-processes) D is a depolarization factor.

- Cuts on inclusive variables: Q² >1 (GeV/c)² (Scale of the process) 0.1 < y < 0.9
- Cuts on hadronic variables: $p_{T1} > 0.7 \text{ GeV/c and } p_{T2} > 0.7 \text{ GeV/c}$ $x_{F1,2} > 0, z_{1,2} > 0, z_1 + z_2 < 0.95$ inv. mass of two hadrons > 1.5 (GeV/c)²

Total number of events in the selected sample: ~500 kevents 2002-2004 data



2 variables o_1 and o_2 are used (R's sum up to 1)



EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek New results on quark helicity distributions and gluon polarization from COMPASS

Data/MC comparison



Comparison: MC/data for high p_T sample; x,y and Q^2

Data/MC comparison



New results on quark helicity distributions and gluon polarization from COMPASS

Results

$$\frac{\Delta G}{G} = 0.08 \pm 0.10 \pm 0.05$$

$$x_G = 0.082^{+0.041}_{-0.027} @\mu^2 \approx 3(GeV/c)^2$$



$\Delta G/G$ from open-charm channel



EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek New results on quark helicity distributions and gluon polarization from COMPASS



- Events considered (resulting from c quarks fragmentation):
 - $D^0 \rightarrow K\pi$ (BR: 4%)
 - $D^* \to D^0 \pi_{_{\mathrm{S}}} \to \mathrm{K} \pi \pi_{_{\mathrm{S}}} (30\% D^0 \underline{tagged with} D^*)$
- Selection to reduce the combinatorial background:
 - Kinematical cuts: Z_{D} , D^{0} decay angle, K and π momentum
 - RICH identification: K and π ID + electrons rejected from the π_{e} sample



D⁰ and D^{*} meson reconstruction, 2002-2004 and 2006 data

Thick target - no D⁰ vertex reconstruction

D⁰ reconstruction: $K\pi$ invariant mass + cuts on D⁰ decay angle + z_D + RICH particle identification (different likehoods)





Due to weighted method spectra are not optimized!

D⁰ and D^{*} meson reconstruction, 2002-2004 and 2006 data

Thick target - no D⁰ vertex reconstruction

D⁰ reconstruction: $K\pi$ invariant mass + cuts on D⁰ decay angle + z_D + RICH particle identification (different likehoods)



a₁₁ is dependent on full knowlege of partonic kinematics:

•
$$a_{LL} = \frac{\Delta \sigma^{PGF}}{\sigma_{PGF}} (y, Q^2, x_g, z_C, \phi)$$

- Can't be experimentally obtained!⇒ only one charmed meson is reconstructed
- a_{LL} is obtained from Monte-Carlo (*in LO*), to serve as input for a Neural Network parameterization on reconstructed kinematical variables: y, x_{Bi}, Q², z_D and p_{T D}

- 82% correlation NN/MC
- very large dispersion of values, even change of sign: weighting essential



- Two real data samples (with same cuts) are compared by the Neural Network (giving as input some kinematic variables as a learning vector):
 - Signal model \rightarrow gcc = K⁺ $\pi^{-}\pi_{s}^{-}$ + K⁻ $\pi^{+}\pi_{s}^{+}$ (D^{*} spectrum: <u>signal + bg</u>.)
 - **Background model** \rightarrow wcc = K⁺ $\pi^{+}\pi_{s}^{-}$ + K⁻ $\pi^{-}\pi_{s}^{+}$
- If the background model is good enough: Net is able to distinguish the signal from the combinatorial background on a event by event basis!

 π^0 reflection in bins of Σ

- Σ is built in the same way as for main channels, **BUT**:
 - Only 1variable is used: Neural Network output
 - Sorts the events according to similar kinematic dependences (thus improving our statistical precision)
 - Results from 2 real data samples comparison, in a mass window around the meson mass



32

 $\Sigma = \frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}}$

EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek

∆G/G results



$\Delta G/G = -0.49 \pm 0.27 \text{ (stat)} \pm 0.11 \text{ (syst)}$

Source	Dº	D∗
Beam polar	0.025	0.025
Target polar	0.025	0.025
Dil. Fact.	0.025	0.025
False asymmetry	0.05	0.05
Signal extraction (Σ)	0.07	0.01
a ₁₁ (charm mass)	0.05	0.03
TOTAL	0.11	0.07

$$\langle x_g \rangle = 0.11^{+0.11}_{-0.05}$$

 $\langle \mu^2 \rangle = 13 \, GeV^2$

published: PLB676(2009)31

EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek

Systematics :

New preliminary result including all channels $\Delta G/G = -0.39 \pm 0.24$ (stat)

 $\Delta G/G$ results

published: $\Delta G/G = -0.49 \pm 0.27 \text{ (stat)} \pm 0.11 \text{ (syst)}$ $\langle x_g \rangle = 0.11^{+0.11}_{-0.05} \langle \mu^2 \rangle = 13 \text{ GeV}^2$

10% gain in statistical precision!

EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek





Summary

- New inclusive and semi-inclusive results (A1 and hadron asymmetries) from COMPASS proton data have been presented
- The evaluation of the first moment of non-singlet g₁ structure function confirms the validity of Bjorken sum rule
- Proton data allows to perform a full flavour separation
- Small value of $\Delta G/G$ is preferred $\Delta G/G$ compatible with 0 within 2σ
- Under study for $\Delta G/G$:
 - pure NN approach (fit independent) and NLO for open-charm
 - 2006 data for high-p_T hadron pairs analysis



Spares

EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek



First moment of g₁

Compass only

Phys.Lett.B 647 (2007)8

 $\Gamma_1^N \left(Q_0^2 = 3GeV^2 \right) = \int_0^1 g_1^N (x) dx = 0.050 \pm 0.003(stat) \pm 0.003(evol) \pm 0.005(syst)$

$$\Gamma_1^N(Q^2) = \frac{1}{9} \left(1 - \frac{\alpha_s(Q^2)}{\pi} + O(\alpha_s^2) \right) \left(a_0(Q^2) + \frac{1}{4}a_8 \right)$$

from Y. Goto *et al.*, PRD62 (2000) 034017: (SU(3)_f assumed for weak decays) $a_8 = 0.585 \pm 0.025$

$$a_{0|Q_0^2=3(GeV/c)^2} = 0.35 \pm 0.03(stat) \pm 0.05(syst)$$
 QCD NLO

$$\Gamma_1^N(Q^2) = \frac{1}{9}C_1^S(Q^2)\hat{a}_0 + \frac{1}{36}C_1^{NS}(Q^2)a_8 \qquad \begin{array}{c} C_1 C_2 \\ S.A.L \\ C_1 C_2 \\ S.A.L \end{array}$$

C₁ calculated behind 3 loops app. S.A.Larin *et al*.,Phys.Lett.B404(1997)153

$$a_{0|Q^2 \to \infty} = 0.33 \pm 0.03(stat) \pm 0.05(syst) \qquad \text{beyond NLO}$$

$$(\Delta s + \Delta \overline{s}) = \frac{1}{3}(\hat{a}_0 - a_8) = -0.08 \pm 0.01(stat) \pm 0.02(syst)$$

Inclusive DIS asymmetry A₁ and g₁

3 years of deuteron data taking 2002-2004 : 89*10⁶ events



No tendency towards negative values at x < 0.03

EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek New results on quark helicity distributions and gluon polarization from COMPASS

Difference asymmetries

$$\Gamma_{v} = \int_{0}^{1} (\Delta u_{v}(x) + \Delta d_{v}(x)) dx$$

 $\Delta \overline{u} + \Delta \overline{d} = 3\Gamma_1^N - \frac{1}{2}\Gamma_v + \frac{1}{12}a_8 = (\Delta s + \Delta \overline{s}) + \frac{1}{2}(a_8 - \Gamma_v)$



New results on quark helicity distributions and gluon polarization from COMPASS

OMPAS

MC simulations

- 2 MC samples were used in the analysis: high- p_T and inclusive
- Input: LEPTO generator and full simulation of the detector PDFs: MRST2004LO
- Gluon radiations in final and initial states simulation of the part of NLO corrections:
 - Parton Shower on were used for DG/G extraction (means NN training)
 - Parton Shower off were tested and included in the systematics
- To improve data/MC agreement LEPTO was tuned (k_T and parameters of fragmentation)
- Default MC parameters were used in systematics studies

	PARJ21	PARJ23	PARJ214	PARJ41	PARJ42
Default	0.36	0.01	2.0	0 .3	0.58
Compass	0.3	0.02	3.5	0.6	0.1

	Final MC
<a<sup>LO></a<sup>	0.63
< a ^c >	0.50
<a<sup>PGF></a<sup>	-0.36
R_{L}	0.40
R_{C}	0.29
R_{PGF}	0.31

- Because the channel is very clean from background contamination (due to a 3-body mass cut), the following contributions can be added:
 - π^0 reflection "bump": **D**⁰ → **K**ππ⁰ ⇒ Mass window increased to ± 600 MeV/c² to obtain a better fit on the bump!
 - RICH sub-threshold Kaons events: Include candidates with no positive pion or electron ID
- Signal strength parameterization $(\Sigma = S/(S+B))$:

 $\Sigma = \frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}}$

- Problem:
 - Low purity samples with low statistics ⇒ Very difficult to build Σ in several bins of several variables
- Solution:
 - Multi-dimentional parameterization using a Neural Network (all kinematic and RICH dependences taken into account at same time)

∆G/G results

Preliminary results including all channels



Final result (no systematic contribution is available yet for the new channels):

$$\frac{\Delta G}{G} = -0.39 \pm 0.24 \text{ (stat)} \quad @<\mathbf{x}_g> = 0.11, <\mu^2> = 13 \text{ GeV}^2$$
10 % improvement in our statistical significancy

Why measure gluon spin from Open-Charm?

 cc production is dominated by the PGF process, and <u>free from physical</u> <u>background</u> (ideal for probing gluon polarisation)



Intrinsic charm predictions: CTEQ6.5c

- In the COMPASS kinematic domain:
 - No intrinsic charm contamination is predicted by the theory driven results
 - Only the more phenomenological "See-like" scenario should be taken into account (under study)



Validation of parameterization (2006 example)



EPS HEP 2009, 16- 22 July, Krakow, Poland Krzysztof Kurek New results on quark helicity distributions and gluon polarization from COMPASS

COMPASS 46