Measurement of the structure function g_1^p with 200 GeV beam at COMPASS (CERN)

Artem Ivanov
on behalf of the COMPASS Collaboration

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   - Polarised deep inelastic scattering
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   - Asymmetry calculation
4. **Results**
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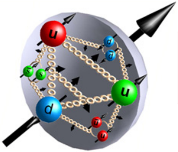
Nucleon spin



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{(q+g)}$$

quark gluon orbital momentum

- Naive Quark-Parton Model: $\Delta\Sigma = \Delta u + \Delta d = 1$
- Relative Quark-Parton Model: $\Delta\Sigma \approx 0.6$

But!

In 1988 EMC measured the quarks contribution to the spin of the nucleon to be very small:

$$\Delta\Sigma = 0.12 \pm 0.17(\text{stat})$$

(EMC, Nucl. Phys. B 328(1989) 1)

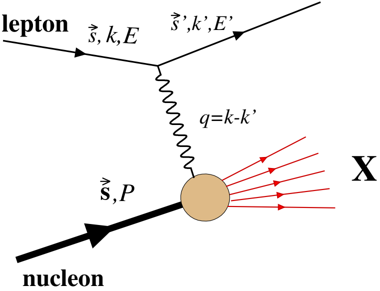
- Present world data:

$$\Delta\Sigma = 0.30 \pm 0.01(\text{stat})$$

(COMPASS, Phys. Lett. B 690(2010) 466)

Inclusive deep-inelastic scattering

$$l + N \rightarrow l' + X$$



- Virtual-photon kinematics: $Q^2 = -q^2$, $\nu = E - E'$
- Fraction of the nucleon momentum carried by struck quark: $x \equiv x_{Bj} = \frac{Q^2}{2M\nu}$
- Fractional energy transfer to the nucleon: $y = \frac{\nu}{E}$

Inclusive cross section

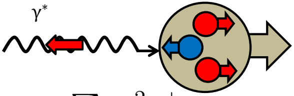
$$\frac{d^2\sigma}{d\Omega dE'} \sim \underbrace{c_1 F_1(x,Q^2) + c_2 F_2(x,Q^2)}_{\text{spin independent}} + \underbrace{c_3 g_1(x,Q^2) + c_4 g_2(x,Q^2)}_{\text{spin dependent}}$$

Polarised deep inelastic scattering

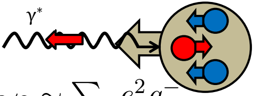
- **Longitudinal spin asymmetry** (can be measured in an experiment)

$$A_{||} = \frac{d\sigma^{\uparrow\Downarrow} - d\sigma^{\uparrow\Uparrow}}{d\sigma^{\uparrow\Downarrow} + d\sigma^{\uparrow\Uparrow}} \simeq D(\mathbf{A_1} + \eta A_2), \quad D \simeq \frac{2y - y^2}{2(1-y)(1+R)+y}$$

- **Absorption of polarised photons (QPM)**



$$\sigma_{1/2} \sim \sum_f e_f^2 q^+$$



$$\sigma_{3/2} \sim \sum_f e_f^2 q^-$$

Quark densities:

$$q(x) \equiv q^+(x) + q^-(x)$$
$$\Delta q(x) \equiv q^+(x) - q^-(x)$$

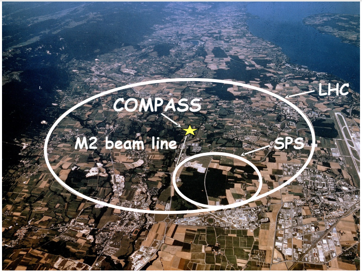
$q^{\pm}(x)$ spins of quark and nucleon follow in the same (opposite) direction.

- **Photon-nucleon asymmetry**

$$\mathbf{A_1}(x,Q^2) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_f e_f^2 \Delta q(x)}{\sum_f e_f^2 q(x)} = \frac{g_1(x,Q^2)}{F_1(x,Q^2)} = \frac{2x(1+R)}{F_2(x,Q^2)} g_1(x,Q^2)$$

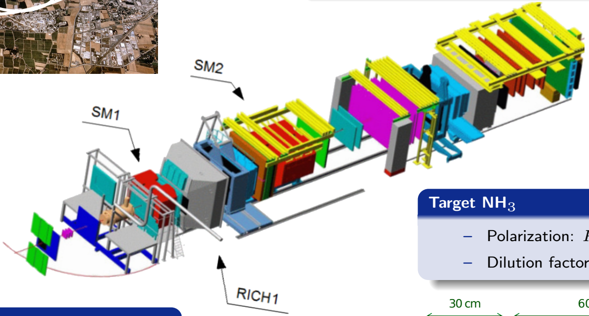
Measurement of $\mathbf{A_1}$ gives access to spin dependent structure functions g_1.

COMPASS spectrometer



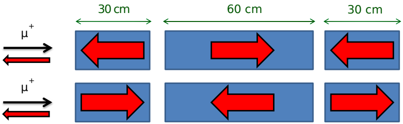
Spectrometer

- Two magnets (1 Tm, 4.5 Tm)
- Tracking ($p > 0.5$ GeV/c): SciFi, Silicon, MicroMega, GEM, MWPC, DC, Straw;
- Electromagnetic and Hadron Calorimeters
- Large acceptance 180 mrad



Target NH_3

- Polarization: $P_T \approx 85\%$
- Dilution factor: $f \approx 0.16$



Polarised μ^+-beam

- $1 \cdot 10^8 (2 \cdot 10^2)$ μ per spill of $\sim$ 10 s
- Energy: 200 GeV (160 GeV)
- Polarization: $P_B \approx 76 - 80\%$

DIS event selection

2011 data

General cuts:

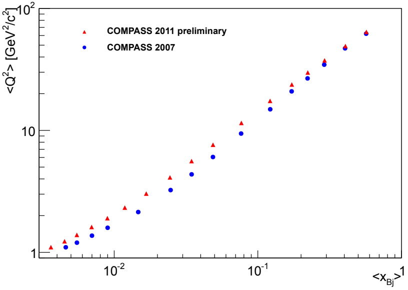
- Primary vertex is in the target and has incoming μ and scattered μ
- Beam μ has to pass all target cells

Kinematic cuts:

- $Q^2 > 1$ (GeV$/c)^2$
- $0.1 < y < 0.9$
- 180 GeV $< E_\mu <$ 220 GeV
- $0.0025 < x < 0.7$

Statistics available for the analysis:

$78 \cdot 10^6$ events



2007 data

- 140 GeV $< E_\mu <$ 180 GeV
- $0.004 < x < 0.7$

The total statistics:

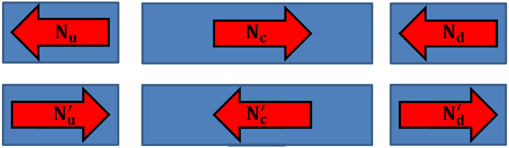
$85.3 \cdot 10^6$ events

Asymmetries calculation

Weighted method: $P = \sum_i^N \omega_i$

Number of interactions: $N = a\Phi n\bar{\sigma}(1 \pm \overbrace{fDP_B}^{\omega-\text{weight}} P_T \mathbf{A_1})$

- a – acceptance
- Φ – beam flux
- $n = n_p + \sum_A n_A$
  full density of nuclei
  of the target material
- $\bar{\sigma} = \frac{\bar{\sigma}_p n_p + \sum_A \bar{\sigma}_A n_A}{n}$
  full cross-section
- $f = \frac{n_p \bar{\sigma}_p}{n\bar{\sigma}}$ – dilution factor
- D – depolarization factor



– Reversal by field rotation every 24h to cancel out acceptance difference

– Reversal by microwave once in a while to cancel out acceptance/field correlation

$$\delta \equiv \frac{P_{(u+d)} P'_c}{P'_{(u+d)} P_c} \Rightarrow a\mathbf{A_1}^2 + b\mathbf{A_1} + c = 0$$

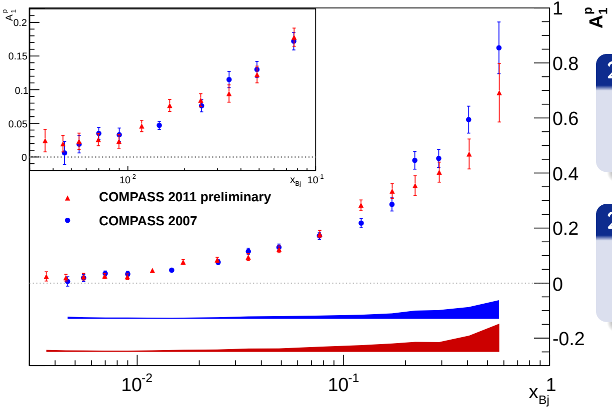
Main sources of systematic error

$$A_1^{1\gamma} = \underbrace{\frac{1}{fDP_BP_T}}_{\text{Multiplicative}} A^{raw} - \underbrace{(A_1^{RC} + \mathcal{O}(\frac{x}{Q}A_2) + \mathcal{O}(A_{false}))}_{\text{Additive}}$$

Beam polarization	dP_B/P_B	5%
Target polarization	dP_T/P_T	5%
Depolarization factor	$dD(R)/D(R)$	2 – 3 %
Dilution factor	df/f	2 %
Total		$\Delta A_1^{mult} \simeq 0.08 A_1$

Transverse asymmetry	$\eta/\rho \cdot \Delta A_2$	$10^{-3} - 10^{-2}$
Radiative corrections	ΔA_1^{RC}	$10^{-5} - 10^{-3}$
False asymmetry	A_{false}	$< (0.36 \div 0.84) \cdot \Delta A_1^{stat}$

Results on inclusive asymmetry A_1^p



2011

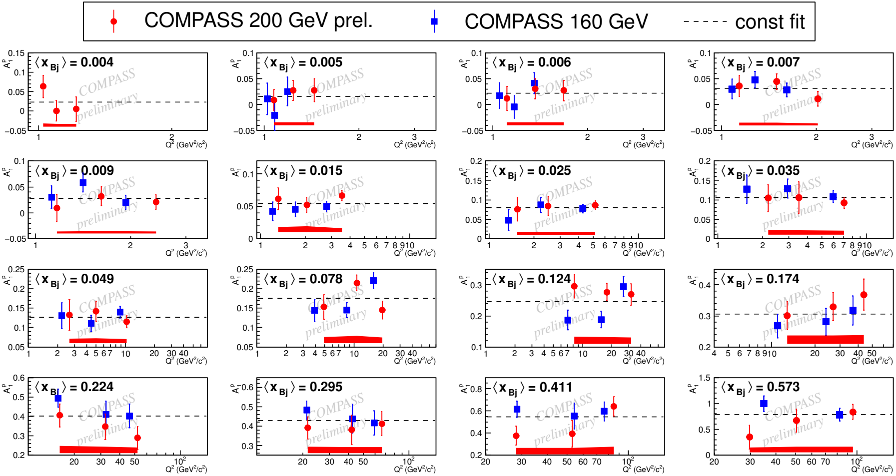
- $180 \text{ GeV} < E_\mu < 220 \text{ GeV}$
- $0.0025 < x < 0.7$

2007

- $140 \text{ GeV} < E_\mu < 180 \text{ GeV}$
- $0.004 < x < 0.7$

- Lower x value reached
- Good agreement between COMPASS 2007 and 2011

Asymmetry A_1^p: Q^2 evolution

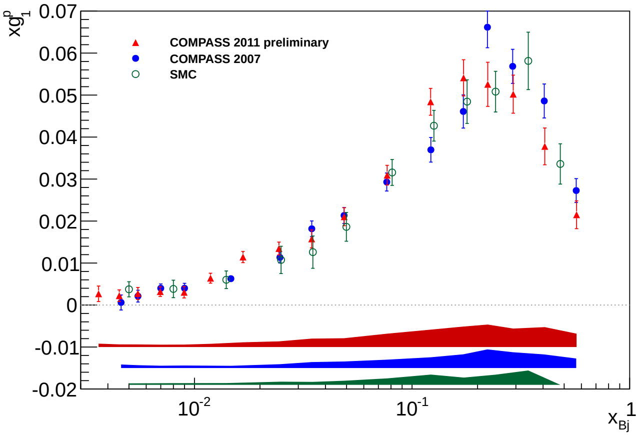


– No significant dependence on Q^2 observed

Results on structure function g_1^p

$$g_1^p(x) = \frac{F_2^p}{2x(1+R)} \mathbf{A_1^p}$$

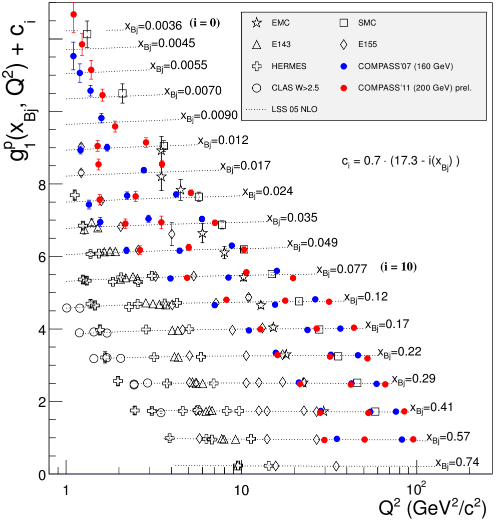
- F_2^p - SMC parametrization
  (SMC PRD 55 (1998) 112001)
- R - SLAC parametrization
  (COMPASS PLB 647 (2007) 330)



- Good agreement between COMPASS 2011/2007 and SMC

Indirect measurement of ΔG, g_1^p via Q^2 evolution

– World data measurement of proton spin structure function $g_1^p(x)$ as a function of Q^2 in bins of x



- COMPASS 160 GeV
- COMPASS 200 GeV
  new data point at very low x

New inputs for global fits and indirect ΔG extraction

LSS'05 fit at next-to-leading order

PRD 73 (2006) 034023

Conclusion and Outlook

Conclusion

- Reduction of the statistical error of g_1^p with the new data at 200 GeV
- Extension of the measured region to lower x and larger Q^2
- For the first time, the results for smaller x $(0.0025 < x < 0.004)$

Outlook

- Update of the Bjorken Sum Rule
- Indirect measurement of ΔG via g_1 COMPASS global fit
- Extraction of $A_{1,p}^{\pi+}$, $A_{1,p}^{\pi-}$, $A_{1,p}^{K+}$ and $A_{1,p}^{K-}$
- Extraction of Δq per flavour

Thank you for your attention