Spin structure of the proton at low x and low Q^2 in two-dimensional bins from COMPASS

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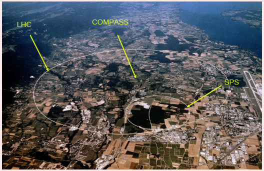
Motivation

- low $x \leftrightarrow$ high parton densities
- low x and low $Q^2 \leftrightarrow$ **transition from the regime of photoproduction to the regime of DIS (described by pQCD)**
- A_1^p and g_1^p as functions of x and ν showed, **for the first time**, **positive spin effects at very low x** (*cf.* $A_1^d \sim 0$ at low x, and SMC sample - 150x smaller)
- theoretical predictions for g_1^p as function of two kinematic variables:
  - Badełek et al., Eur.Phys.J. C26 (2002) 45
    "Spin structure function $g_1(x, Q^2)$ and the DHGHY integral $I(Q^2)$ at low Q^2: Predictions from the GVMD model"
  - Ermolaev et al., Eur.Phys.J. C58 (2008) 29
    "Comment on the recent COMPASS data on the spin structure function g_1"
  - Ermolaev et al., Riv.Nuovo Cim. 33 (2010) 57
    "Overview of the spin structure function g_1 at arbitrary x and Q^2"
    "one can parameterize g_1 by the set of variables x, Q^2 or, alternatively, $\omega[\equiv 2pq = 2M(E - E')]$, Q^2, or ν, Q^2"
- COMPASS' $\sim 7 \times 10^8$ events allow a 2D extraction
- extraction, for the first time, in 4 2D grids: (x, Q^2), (ν, Q^2), (x, ν), (Q^2, x)

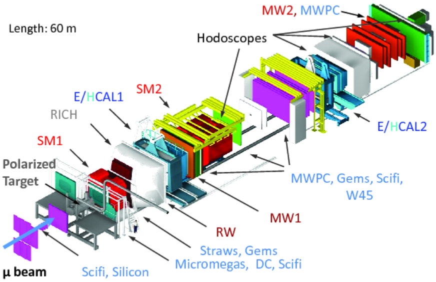
The COMPASS experiment at CERN

COMPASS @ CERN

COmmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy



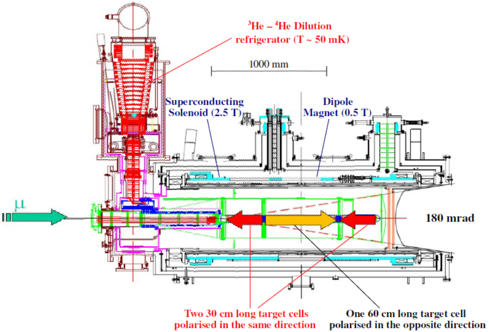
- **Fixed target experiment** at the SPS using a tertiary **muon beam**
- Collaboration of about 200 members from 11 countries and 23 institutions



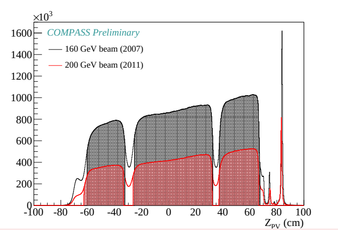
- 160/200 GeV μ^+ **polarised beam**, $P_b \sim -80\%$
- **^{6}LiD** or N**H$_3$**, 1.2 m long, **polarised target** @ 2.5 T and 60 mK, $P_{\text{target}} \sim 50/85\%$

- large acceptance, two staged spectrometer
- tracking, calorimetry, PID

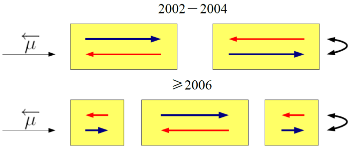
Polarised target



Vertex coordinate z_{PV}



Material	Dilution factor (f)	Polarisation (P_{target})
^{6}LiD	0.40	50%
NH_3	0.16	85%



Data samples for the extraction of A_1^p and g_1^p

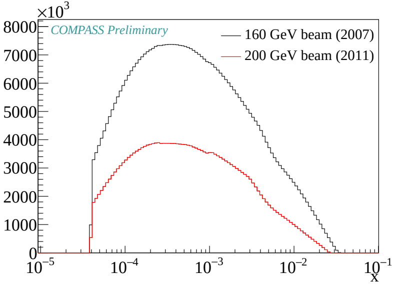
- Longitudinally polarised target (NH_3): **676×10^6 events**
  (447×10^6 with 160 GeV beam in 2007, 229×10^6 with 200 GeV beam in 2011)

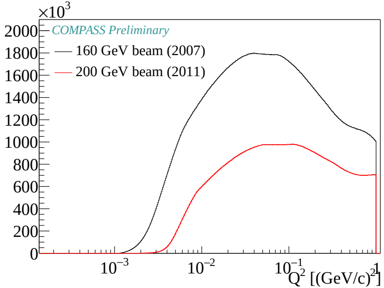
- Before, SMC low x, low Q^2 proton data: 4.5×10^6 events
  $\Rightarrow$ The COMPASS data set has **150**$\times$ more events than SMC

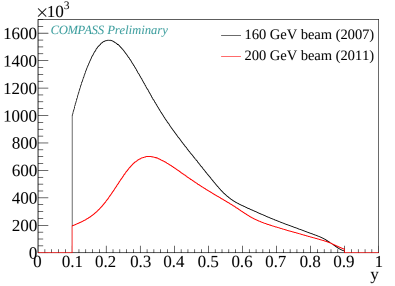
Main selection criteria:

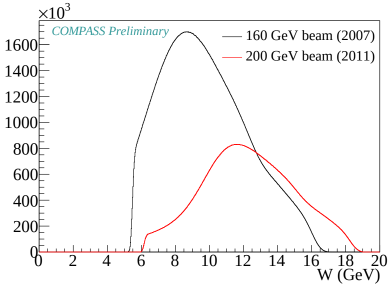
- at least one additional track (besides the scattered muon) in the interaction point ("hadron method") - SMC proved there is no bias to the inclusive asymmetries at low x
- not a μe elastic scattering event
- $Q^2 < 1\ (\text{GeV}/c)^2$
- $x \geq 4 \times 10^{-5}$
- $0.1 < y < 0.9$

Characteristics of the final sample



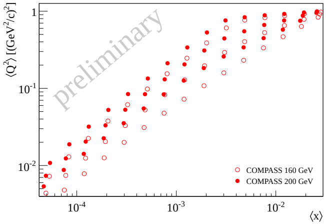




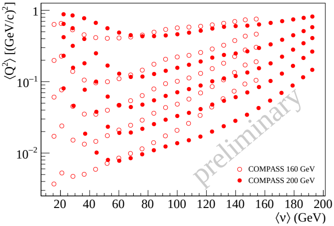


Phase-space coverage of the 2D analysis

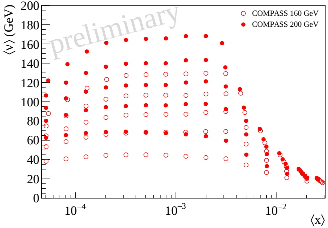
(x, Q^2)



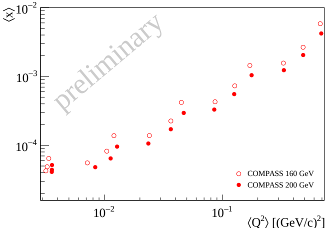
(ν, Q^2)



(x, ν)



(Q^2, x)



Double spin longitudinal asymmetry A_1^p

- $\mathbf{N}^{\overset{\leftarrow}{\Rightarrow},\overset{\leftarrow}{\Leftarrow}} = \mathbf{a}\phi\mathbf{n}\bar{\sigma}(\mathbf{1} \pm \mathbf{P}_{\text{beam}}\mathbf{P}_{\text{target}}\mathbf{f}\,\mathbf{D}\,\mathbf{A}_1^p)$ $\quad \dfrac{\mathbf{N}^{\overset{\leftarrow}{\Rightarrow},1} \cdot \mathbf{N}^{\overset{\leftarrow}{\Rightarrow},2}}{\mathbf{N}^{\overset{\leftarrow}{\Leftarrow},1} \cdot \mathbf{N}^{\overset{\leftarrow}{\Leftarrow},2}} \to 2^{\text{nd}}$ ord. eq. on $\mathbf{A}_1^p$

- Each event is given a weight $\omega = \mathbf{f}\,\mathbf{D}|\mathbf{P}_{\text{beam}}|$ to optimize the statistical errors

- Unpolarised radiative corrections (RC), included in the dilution factor, from TERAD

  [A.A. Akhundov, *et al.*, Fortschr. Phys. 44 (1996) 373]

- Polarised radiative corrections ($A^{\text{RC}} \leq 0.25\,\delta A_1^{\text{stat}}$) from POLRAD

  [I. Akushevich *et al.*, Comput.Phys.Commun. 104 (1997) 201]

- Corrected for polarisable ^{14}N ($A^{^{14}\text{N}} \leq 0.01\,\delta A_1^{\text{stat}}$)

- Thorough checks on possible sources of false asymmetries ⇒ systematic errors similar to the statistical errors

Spin dependent structure function g_1^p

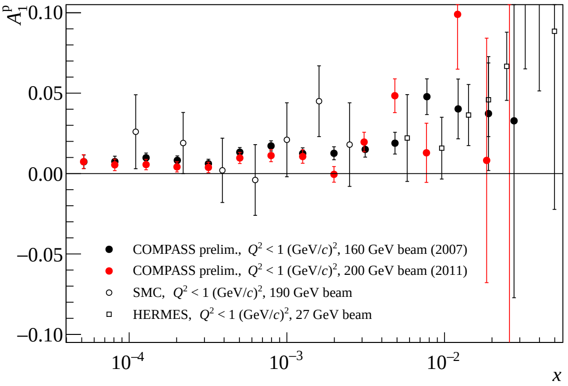
- The structure function is obtained in bins of x or ν according to:

$$\mathbf{g_1^p}\left(\langle \mathbf{x}\rangle, \langle \mathbf{Q^2}\rangle\right) = \frac{\mathbf{F_2^p}\left(\langle \mathbf{x}\rangle, \langle \mathbf{Q^2}\rangle\right)}{\mathbf{2x}\left[\mathbf{1} + \mathbf{R}\left(\langle \mathbf{x}\rangle, \langle \mathbf{Q^2}\rangle\right)\right]} \mathbf{A_1^p}\left(\langle \mathbf{x}\rangle, \langle \mathbf{Q^2}\rangle\right)$$

- $\mathbf{F_2^p}(\langle \mathbf{x}\rangle, \langle \mathbf{Q^2}\rangle)$ from the SMC fit on data or from a model (for low x and Q^2)
  [SMC, Phys.Rev. D58 (1998), 112001; B. Badełek & J. Kwieciński, Phys.Lett. B295 (1992) 263]

- $\mathbf{R}(\langle \mathbf{x}\rangle, \langle \mathbf{Q^2}\rangle)$ based on SLAC parameterization, extended to low Q^2
  [COMPASS, PLB 647 (2007) 330]

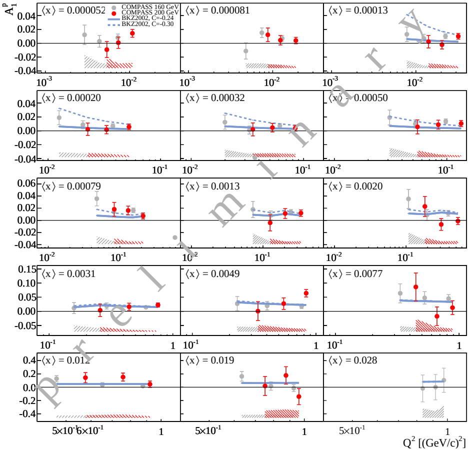
$A_1^p(x)$ & comparison with previous experiments

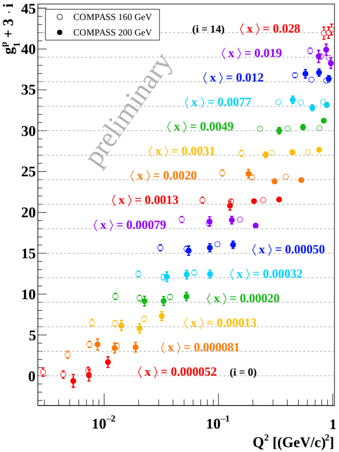


- results for the two beam energies are compatible within errors
- systematic errors are similar to the statistical errors (not shown here)
- A_1^p is **significantly positive**
- no dependence on x is seen (nor on ν, not shown here)
- the COMPASS results **improve the precision** of the measurement

A_1^p and g_1^p at low x and low Q^2: results for the grid (x, Q^2)

Data: 2007&2011, $\mu^+ p \to \mu^+ X$

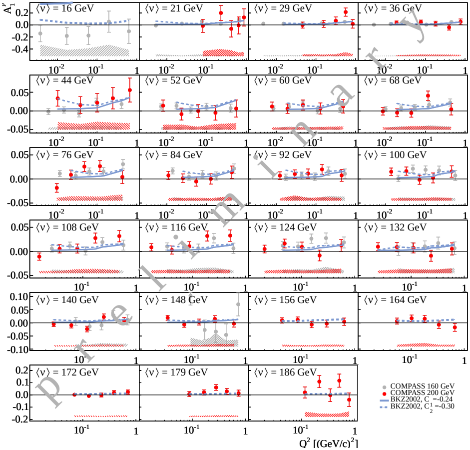


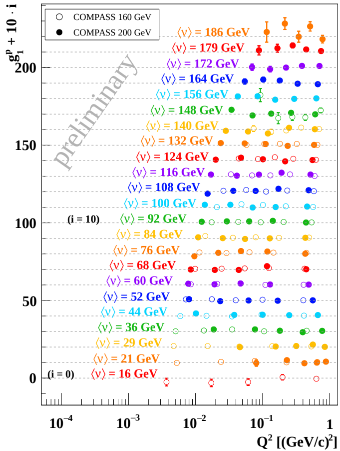


- **no strong dependence** on x or Q^2
- results **compatible with theoretical model (GVMD)** [Eur.Phys.J. C26 (2002) 45]

A_1^p and g_1^p at low x and low Q^2: results for the grid (ν, Q^2)

Data: 2007&2011, $\mu^+ p \to \mu^+ X$

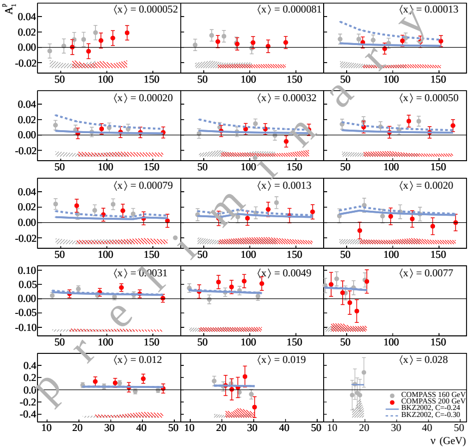


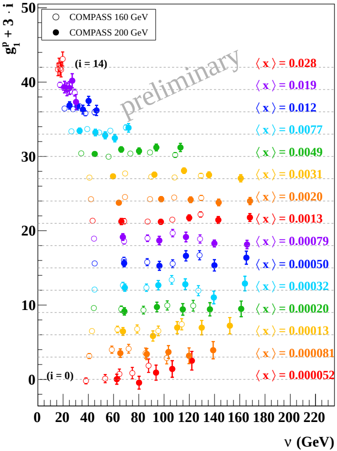


- **no strong dependence** on ν or Q^2
- results **compatible with theoretical model (GVMD)** [Eur.Phys.J. C26 (2002) 45]

A_1^p and g_1^p at low x and low Q^2: results for the grid (ν, x)

Data: 2007&2011, $\mu^+ p \to \mu^+ X$

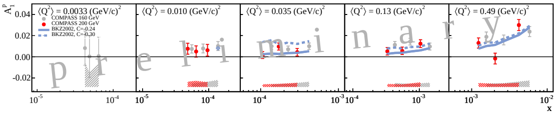


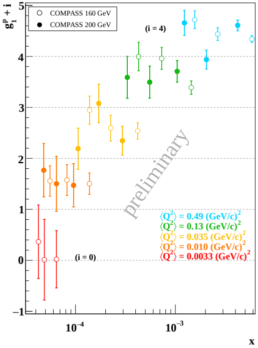


- **no strong dependence** on ν or x
- results **compatible with theoretical model (GVMD)** [Eur.Phys.J. C26 (2002) 45]

A_1^p and g_1^p at low x and low Q^2: results for the grid (Q^2, x)

Data: 2007&2011, $\mu^+ p \to \mu^+ X$





- **no strong dependence** on x or Q^2
- results **compatible with theoretical model (GVMD)** [Eur.Phys.J. C26 (2002) 45]

Summary and outlook

- Longitudinal double spin asymmetries $\mathbf{A}_1^p$ and the spin dependent structure function $\mathbf{g}_1^p$ extracted in 4 two-dimensional grids:
  - (x, Q^2)
  - (ν, Q^2)
  - (x, Q^2)
  - (Q^2, x)
- **Positive** spin asymmetries at very low x
- **No significant dependence** on studied kinematic variables
- **Compatibility with GVMD model** predictions [Eur.Phys.J. C26 (2002) 45]

BACKUP

GVMD model [Eur.Phys.J. C26 (2002) 45]

[Badełek et al., Eur.Phys.J. C26 (2002) 45]

$$
\begin{aligned}
g_1(x,Q^2) &= g_1^{\mathrm{L}}(x,Q^2) + g_1^{\mathrm{AS}}(\bar{x},Q^2+Q_0^2) \\
&= C\left[\frac{4}{9}(\Delta u_{\mathrm{val}}^{(0)}(x) + \Delta\bar{u}^{(0)}(x)) \right. \\
&\quad \left. + \frac{1}{9}(\Delta d_{\mathrm{val}}^{(0)}(x) + \Delta\bar{d}^{(0)}(x))\right]\frac{M_\rho^4}{(Q^2+M_\rho^2)^2} \\
&\quad + C\left[\frac{1}{9}(2\Delta\bar{s}^{(0)}(x))\right]\frac{M_\phi^4}{(Q^2+M_\phi^2)^2} \\
&\quad + g_1^{\mathrm{AS}}(\bar{x},Q^2+Q_0^2). \qquad (5)
\end{aligned}
$$

To obtain the value of C from (12), the contribution of resonances was evaluated using the preliminary data taken at ELSA/MAMI by the GDH Collaboration [16] at the photoproduction, for $W_t = 1.8\,\mathrm{GeV}$. The asymptotic part of g_1 was parametrized using the GRSV2000 fit for the "standard scenario" of polarized parton distributions with a flavor symmetric light sea, $\Delta\overline{u} = \Delta\overline{d} = \Delta s = \Delta\overline{s}$, at the NLO accuracy [9]. The non-perturbative parton distributions, $\Delta p_j^{(0)}(x)$, in the light vector meson component of g_1, (3), were evaluated at fixed $Q^2 = Q_0^2$, using, either
(i) the GRSV2000 fit, or
(ii) a simple, "flat" input:

$$\Delta p_i^{(0)}(x) = N_i(1-x)^{\eta_i}, \qquad (13)$$

with $\eta_{u_v}=\eta_{d_v}=3$, $\eta_{\bar{u}}=\eta_{\bar{s}}=7$ and $\eta_g=5$. The normalization constants N_i were determined by imposing the Bjorken sum rule for $\Delta u_v^{(0)} - \Delta d_v^{(0)}$, and requiring that the first moments of all other distributions are the same as those determined from the QCD analysis [18]. It was checked that the parametrization (13) combined with the unified equations gives a reasonable description of the SMC data on $g_1^{\mathrm{NS}}(x,Q^2)$ [19] and on $g_1^p(x,Q^2)$ [5]. This fit was also used to investigate the magnitude of the double logarithmic corrections, $\ln^2(1/x)$, to the spin structure function of the proton at low x [20]. We have assumed $Q_0^2 = 1.2\,\mathrm{GeV}^2$, cf. (1) and (3), in accordance with the analysis of F_2 [7,8]. As a result the constant C was found to be -0.30 in case (i) and -0.24 in case (ii). These values change at most by 13% when Q_0^2 changes in the interval $1.0 < Q_0^2 < 1.6\,\mathrm{GeV}^2$.

GVMD model predictions [Eur.Phys.J. C26 (2002) 45]

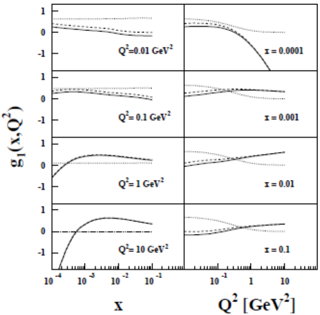


Fig. 1. Values of g_1 for the proton as a function of x and Q^2. The asymptotic contribution, g_1^{AS}, is marked with broken lines, the VMD part, g_1^L, with dotted lines and the continuous curves mark their sum, according to (5)

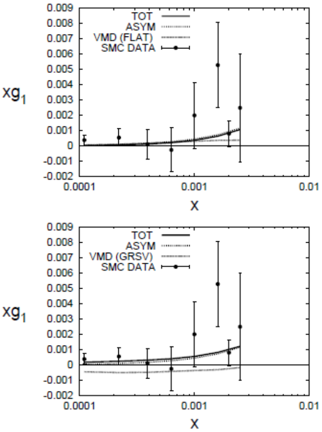


Fig. 2. Values of xg_1 for the proton as a function of x at the measured values of Q^2 in the non-resonant region, $x < x_t = Q^2/2M\nu_t(Q^2)$. The upper plot corresponds to the VMD part parametrized using (13), the lower plot corresponds to the GRSV parametrization [9] of the VMD input. The g_1^{AS} in both plots has been calculated using the GRSV fit for standard scenario at the NLO accuracy. The contributions of the VMD and of the xg_1^{AS} are shown separately. Points are the SMC measurements at $Q^2 < 1\,\text{GeV}^2$ [3]; errors are total. The curves have been calculated at the measured x and Q^2 values