First results on A_1^p and g_1^p at low x and low Q^2 from COMPASS

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on behalf of the COMPASS Collaboration

DIS2014, Warsaw, Poland
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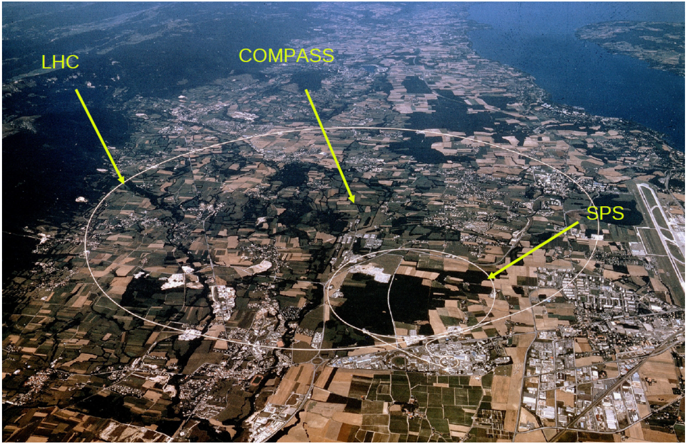
Outline

The COMPASS experiment

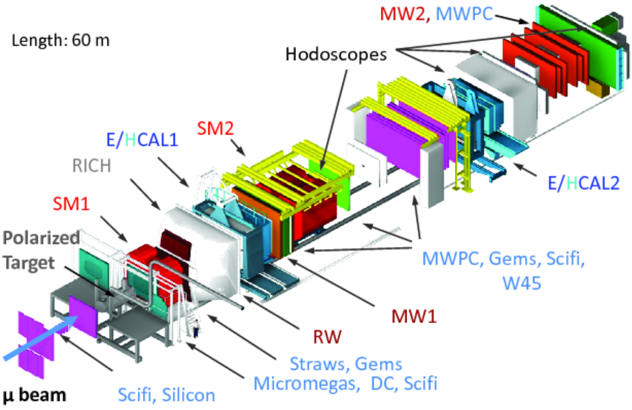
COMPASS @ CERN

[COmmon Muon Proton Apparatus for Structure and Spectroscopy]



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

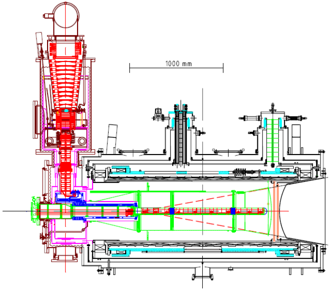
COMPASS spectrometer

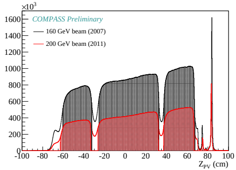


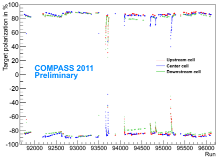
- 160/200 GeV μ^+ naturally **polarised beam** with $P_{\text{beam}} \sim -80\%$
- ^{6}Li**D** or N**H$_3$**, 1.2 m long, **polarised target**

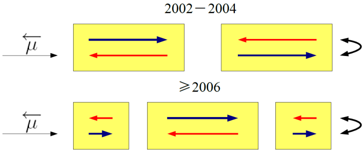
- large acceptance, two staged spectrometer
- tracking
- calorimetry
- RICH

Polarised target









^{6}Li**D** (2002-2006): $f \sim 40\%$, $P_{\text{target}} \sim 50\%$

N**H$_3$** (2007-2011): $f \sim 16\%$, $P_{\text{target}} \sim 85\%$

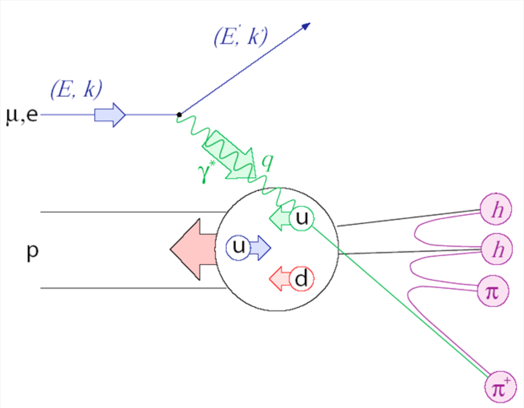
$$\mathbf{N}^{\rightleftarrows,\leftleftarrows} = \mathbf{a}\phi\mathbf{n}\bar{\sigma}(\mathbf{1} \pm \mathbf{P}_{\text{beam}}\mathbf{P}_{\text{target}}\mathbf{f}\,\mathbf{A}_{\parallel})$$

Cancellation of $a\phi n\bar{\sigma}$ via:

- **flux cancellation**
  - reconstructed beam track or extrapolation must cross all target cells
- **acceptance cancellation**
  - 3 target cells (2, before 2006)
  - polarisation rotation every 24 hours (8h, before 2006)
  - grouping of runs in ∼48 h long configurations
  - reversal of "microwave setting" at least once per year

Definitions

Deep inelastic scattering event kinematic variables



Global variables:

$k_\mu = (E_\mu, \mathbf{k}_\mu)$
$k'_\mu = (E'_\mu, \mathbf{k}'_\mu)$
$P = (M, 0)$
$q = \mathbf{k}_\mu - \mathbf{k}'_\mu = (\nu, \mathbf{q})$
$Q^2 = -q^2$
$\nu = P \cdot q/M = E_\mu - E'_\mu$
$W^2 = M^2 + 2M\nu - Q^2$
$x = Q^2/(2M\nu)$
$y = \nu/E_\mu$

Hadron variables:

$p_{\text{lab}} = (E_{\text{lab}}, \mathbf{p}_{\text{had}})$
$z_{\text{had}} = E_{\text{had}}/\nu$

Spin dependent observables

Experimental asymmetry

$$\mathbf{A_{exp}} = \frac{N^{\rightleftarrows} - N^{\rightrightarrows}}{N^{\rightleftarrows} + N^{\rightrightarrows}} = P_{\text{beam}} P_{\text{target}} f\, A_{\parallel}$$

f: dilution factor (of the target)

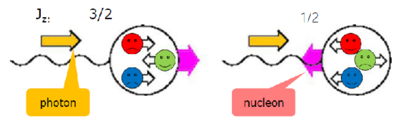
Lepton-nucleon asymmetry

$$A_{\parallel} = \frac{d\sigma^{\rightleftarrows} - d\sigma^{\rightrightarrows}}{d\sigma^{\rightleftarrows} + d\sigma^{\rightrightarrows}} = D(A_1 + \eta A_2)$$

D: (virtual photon) depolarisation factor

η - kinematic variable. COMPASS case: $\eta \sim 0 \Rightarrow \mathbf{A_1} \sim A_{\parallel}/D$

Virtual photon-nucleon asymmetry



$$A_1 = A_1^{\gamma^* N} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1 - \gamma^2 g_2}{F_1} \sim \frac{g_1}{F_1}$$

$$A_2 = \gamma \frac{g_1 + g_2}{F_1} \sim 0$$

γ - kinematic variable (small at COMPASS)

Spin dependent structure function g_1

$$\mathbf{g_1(x, Q^2)} = \frac{F_2(x, Q^2)}{2x(1 + R(x, Q^2))} A_1(x, Q^2), \quad \text{with } R \equiv \sigma_L/\sigma_T$$

Motivation

Motivation for the low x, low Q^2 studies

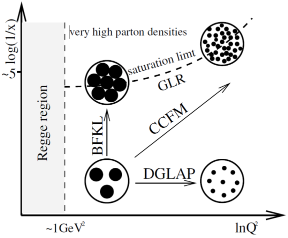
- Low $x \Leftrightarrow$ **high parton densities**

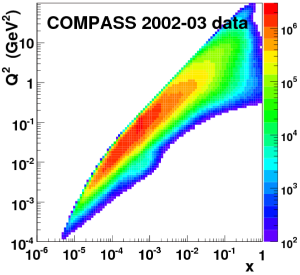
- Fixed target experiments $\Leftrightarrow$ **strong correlation** between x and Q^2: low $x \Rightarrow$ low Q^2, where pQCD isn't expected to work

- Some **models, to be confronted with data**, allow a **smooth extrapolation to the low-Q^2 and high-Q^2 regions** (resummation, VMD):
  B. Badełek et al, B.I. Ermolaev et al.

- A_1^d and g_1^p at low x and low Q^2:
  - can be measured with **improved precision**
  - complement our measurement of A_1^d and g_1^d at low x and low Q^2
  - $g_1^{\mathbf{NS}} = g_1^p - g_1^n$ can be extracted

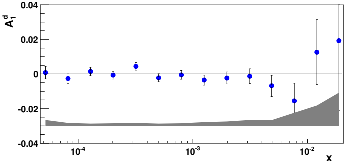
- The results will be presented also as functions of ν, as requested by theoreticians

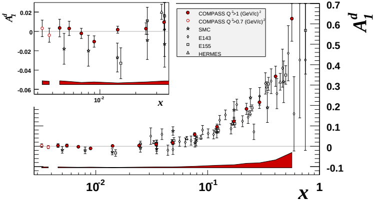


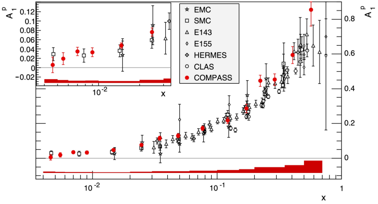


Previous COMPASS results

COMPASS published $A_1^{p,d}$ data

<table>
<tr><th></th><th>$\mathbf{Q^2 < 1\ (GeV/c)^2}$</th><th>$\mathbf{Q^2 > 1\ (GeV/c)^2}$</th></tr>
<tr><td>$\mathbf{A_1^d}$</td><td>

[COMPASS, PLB 647 (2007) 330]</td><td>

[COMPASS, PLB 647 (2007) 8]</td></tr>
<tr><td>$\mathbf{A_1^p}$</td><td>↪ later in this talk</td><td>

[COMPASS, PLB 690 (2010) 466]
↪ more in M. Wilfert's talk</td></tr>
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Data samples

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)

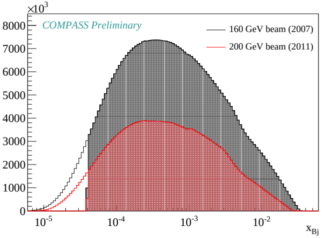
- Before, SMC low x, low Q^2 proton data: 4.5×10^6 events
  $\Rightarrow$ The COMPASS data set has **150**$\times$ more events than SMC

Main selection criteria:

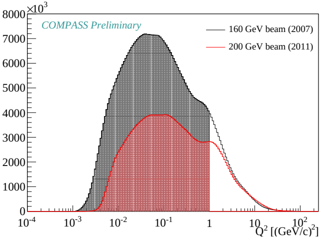
- at least one additional track (besides the scattered muon) in the interaction vertex ("hadron method") - SMC proved there is no bias to the inclusive asymmetries at low x
- not a μe elastic scattering event
- $Q^2 < 1$ (GeV/c)^2
- $x \geq 4 \times 10^{-5}$
- $0.1 < y < 0.9$

Kinematic variables of the final samples

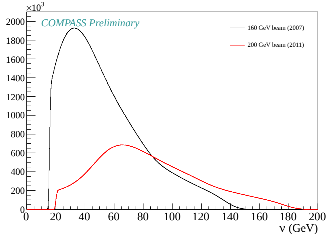
x



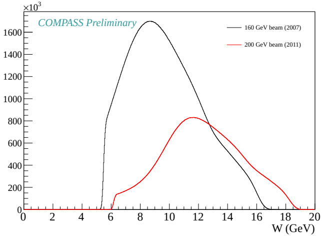
Q^2 $(\text{GeV}/c)^2$



ν (GeV)

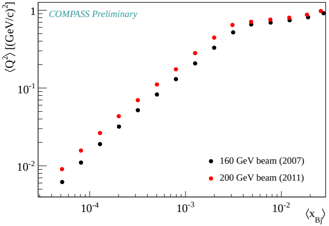


W (GeV)

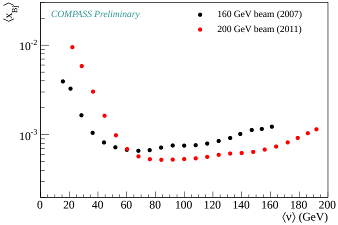


Features of the final samples

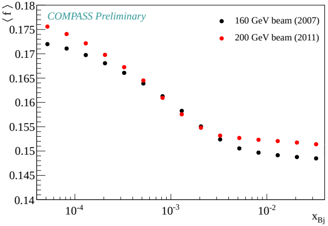
$\langle Q^2 \rangle$ (GeV$^2/c^2$) vs $\langle x \rangle$



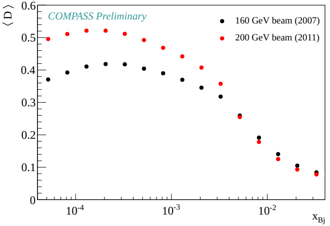
$\langle x \rangle$ vs $\langle \nu \rangle$ (GeV)



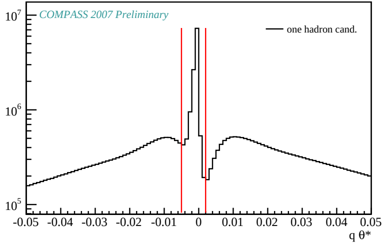
$\langle f \rangle$ vs x

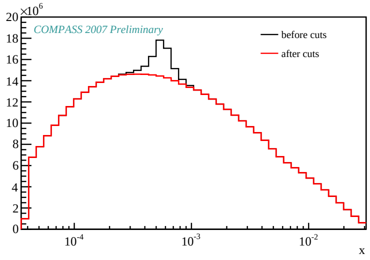


$\langle D \rangle$ vs x



Removal of μe elastic scattering events





$q\theta^* \equiv$ charge $\times$ angle of the track
with respect to the virtual photon direction

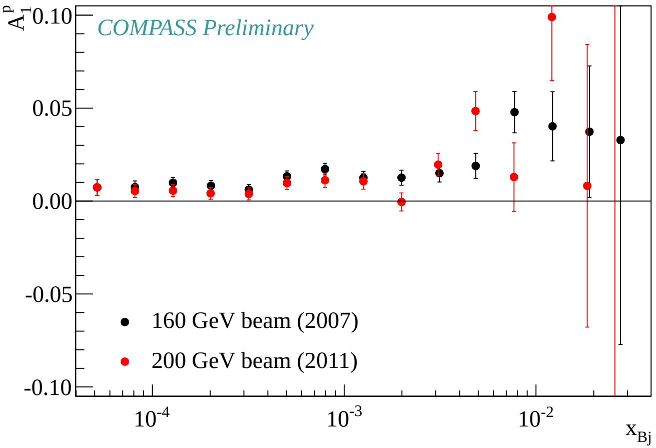
The cut effectively eliminates the μe events from the sample.

Double spin longitudinal asymmetry A_1^p

Double spin longitudinal asymmetry A_1^p

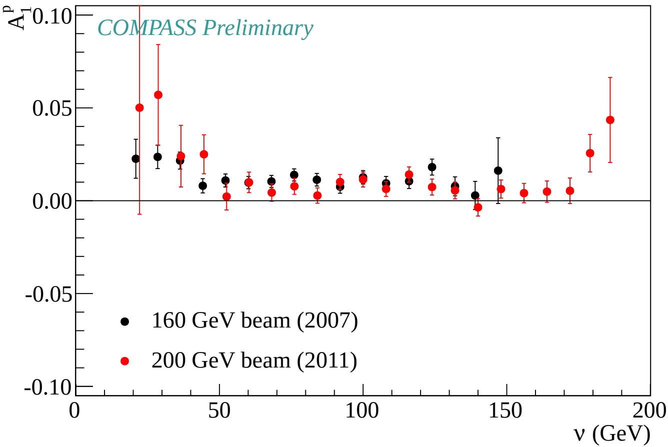
- Obtained giving each event a weight $\omega = \mathbf{f}\,\mathbf{D}|\mathbf{P_b}|$ to optimize the statistical errors of the results
- Unpolarised radiative corrections (RC), included in the dilution factor, from TERAD
  [A.A. Akhundov *et al.*, Sov.J.Nucl.Phys. 26 (1977) 660]
- Polarised radiative corrections ($A^{\mathrm{RC}} \leq 0.25\,\delta A_1^{\mathrm{stat}}$) from POLRAD
  [I. Akushevich *et al.*, Comput.Phys.Commun. 104 (1997) 201]
- Corrected for polarisable ^{14}N ($A^{^{14}\mathrm{N}} \leq 0.01\,\delta A_1^{\mathrm{stat}}$)
- Thorough checks on possible sources of false asymmetries $\Rightarrow$ systematic errors smaller than the statistical errors

First COMPASS results for $A_1^p(x)$ at low x and low Q^2



The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors (not shown here).
A significant positive asymmetry is observed.

First COMPASS results for $A_1^p(\nu)$ at low x and low Q^2



The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors (not shown here).
A significant positive asymmetry is observed.
No significant dependence with ν is seen.

Spin dependent structure function g_1^p

Spin dependent structure function g_1^p

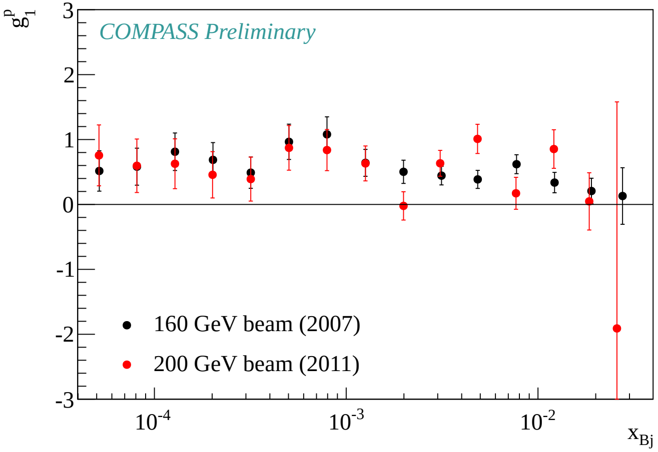
- The structure function is obtained in bins of x or ν according to:

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

- $\mathbf{F_2^p}(\langle\mathbf{x}\rangle,\langle\mathbf{Q^2}\rangle)$ from the SMC fit on data or from a model (for low x and Q^2)
[SMC, Phys.Rev. D58 (1998), 112001; J. Kwieciński & B. Badełek, Z.Phys. C43 (1989), 251; B. Badełek & J. Kwieciński, Phys.Lett. B295 (1992) 263]

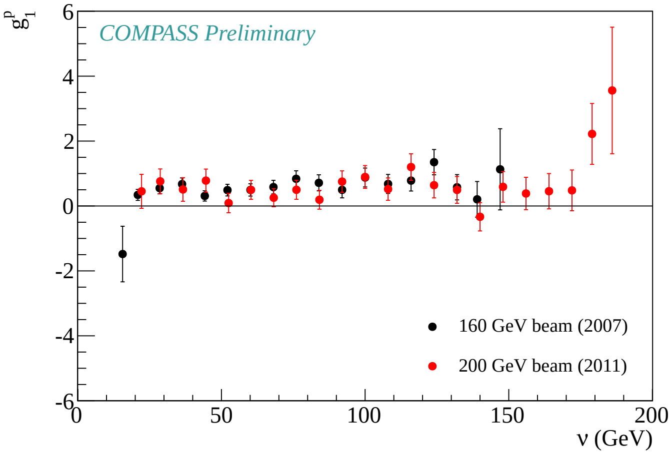
- $\mathbf{R}(\langle\mathbf{x}\rangle,\langle\mathbf{Q^2}\rangle)$ based on SLAC parameterization, extended to low Q^2
[COMPASS, PLB 647 (2007) 330]

First COMPASS results for $g_1^p(x)$ at low x and low Q^2



The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors (not shown here).
g_1^p is **significantly positive**.

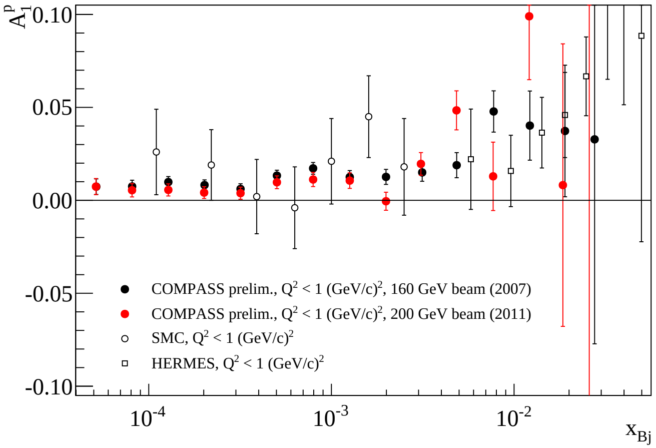
First COMPASS results for $g_1^p(\nu)$ at low x and low Q^2



The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors (not shown here).
g_1^p is **significantly positive**.
No significant dependence with ν is seen.

Comparison with previous experiments

Comparison with previous experiments



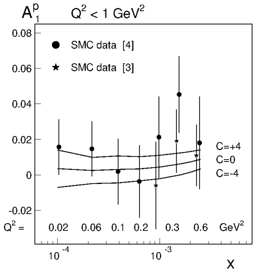
The COMPASS results significantly **improve the precision** of the measurement.

Comparison with model

Comparison with model

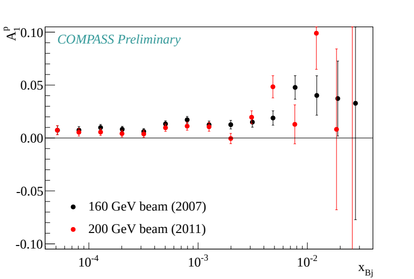
Model: B. Badełek *et al.* [Phys. Rev. D 61 (1999) 014009]

(VMD contribution and QCD improved parton model extended to low Q^2)



$$g_1(x, Q^2) = g_1^{VMD}(x, Q^2) + g_1^{part}(x, Q^2)$$

Parameter C: multiplicative factor relating the VMD contributions and the partonic contributions.



The COMPASS data favour **C** $\in$ **[0, +4]**, *i.e.* a VMD contribution to g_1 of the same sign of the partonic contribution.

Summary

Summary

- A_1^p and g_1^p measured for $0.001 < Q^2 < 1\ (\text{GeV}/c)^2$, $4 \times 10^{-5} < x < 4 \times 10^{-2}$, and $14 < \nu < 194$ GeV, in bins of x or in bins of ν
- Total statistics **150 times larger** than SMC
- Results from data at 160 GeV and 200 GeV are compatible
- Results of A_1^p and g_1^p are **significantly positive**
- $A_1^p(x)$ results are compatible with the model of Badełek et al. (1999) for $\mathbf{C} \in [\mathbf{0}, +\mathbf{4}]$, *i.e.* they favour a VMD contribution to g_1 of the same sign as the partonic one.

BACKUP

Spin independent and spin dependent DIS cross sections

For a **longitudinally/transversely polarised proton target (with spin $\Rightarrow$ and $\Leftarrow$ / $\Uparrow$ and $\Downarrow$)** and a **longitudinally polarised lepton beam (with spin $\rightarrow$)**:

Unpolarised differential cross-section

$$\left(\frac{d^2\sigma^{\overset{\rightarrow}{\Rightarrow}}}{d\Omega dE'} + \frac{d^2\sigma^{\overset{\rightarrow}{\Leftarrow}}}{d\Omega dE'}\right) = \frac{\alpha^2}{4E^2\sin^4\frac{\theta}{2}}\left[2\sin^2\frac{\theta}{2}\mathbf{F_1(x,Q^2)} + \frac{M}{\nu}\cos^2\frac{\theta}{2}\mathbf{F_2(x,Q^2)}\right]$$

Longitudinal differential cross-section asymmetry

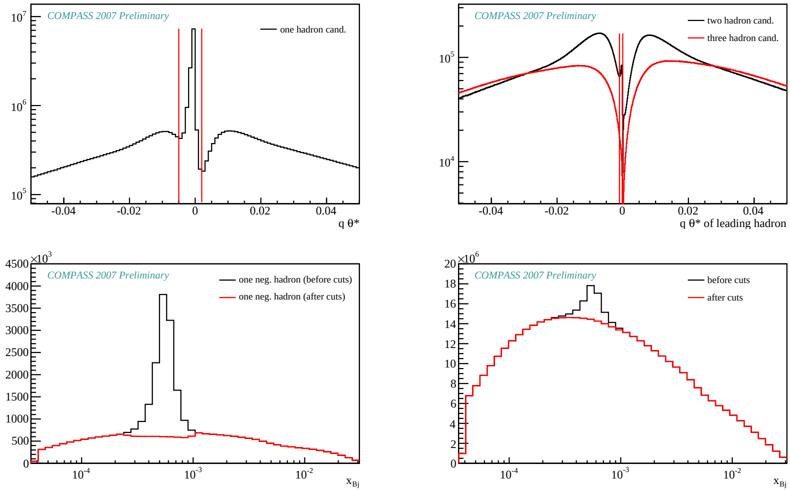
$$\left(\frac{d^2\sigma^{\overset{\rightarrow}{\Rightarrow}}}{d\Omega dE'} - \frac{d^2\sigma^{\overset{\rightarrow}{\Leftarrow}}}{d\Omega dE'}\right) = \frac{4\alpha^2}{M\nu}\frac{E'^2}{Q^2E}\left[(E+E'\cos\theta)\,\mathbf{g_1(x,Q^2)} - 2xM\,\mathbf{g_2(x,Q^2)}\right]$$

Transverse differential cross-section asymmetry

$$\left(\frac{d^2\sigma^{\overset{\rightarrow}{\Uparrow}}}{d\Omega dE'} - \frac{d^2\sigma^{\overset{\rightarrow}{\Downarrow}}}{d\Omega dE'}\right) = \frac{4\alpha^2}{M\nu}\frac{E'^2}{Q^2E}\sin\theta\left[\mathbf{g_1(x,Q^2)} + \frac{2E}{\nu}\mathbf{g_2(x,Q^2)}\right]$$

g_2 term suppressed relative to g_1 term $\Rightarrow$ At COMPASS, a **longitudinally polarised muon beam** and a **longitudinally polarised target with protons** allow the measurement of $\mathbf{g_1(x,Q^2)}$

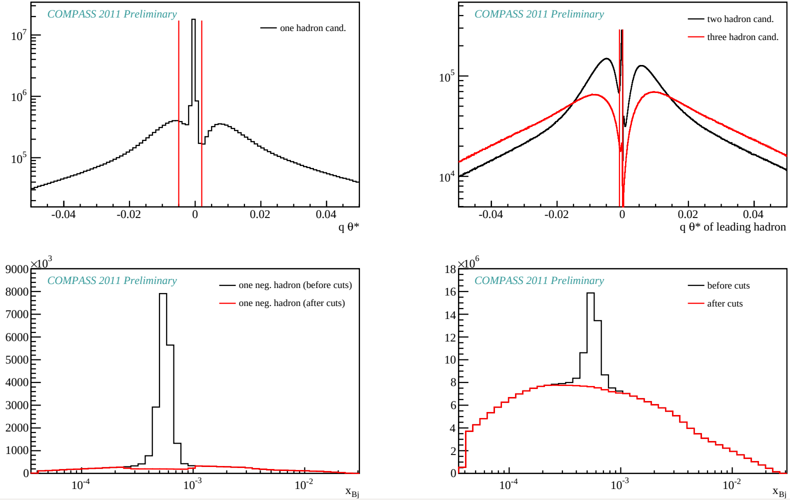
Removal of μe elastic scattering events for 2007 data



$q\theta^*$: charge $\times$ angle of the track with respect to the virtual photon direction

The cut effectively eliminates the μe events from the sample.

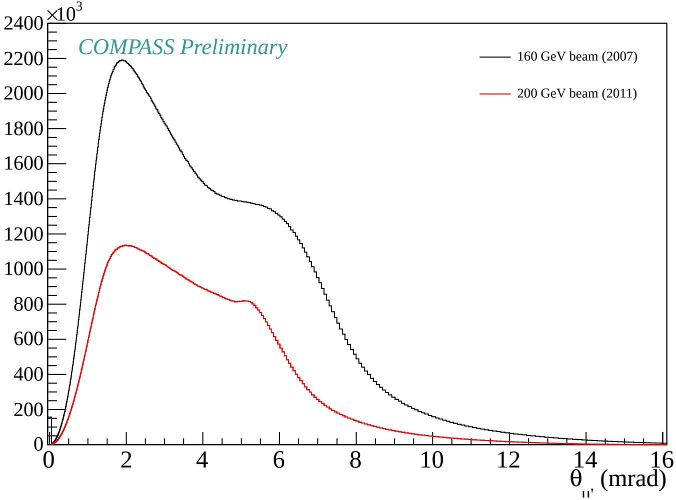
Removal of μe elastic scattering events for 2011 data



$q\theta^*$: charge $\times$ angle of the track with respect to the virtual photon direction

The cut effectively eliminates the μe events from the sample.

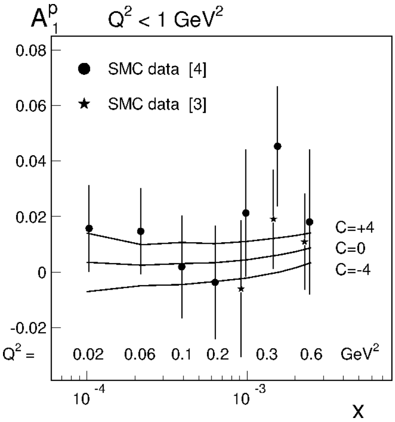
Polar angle of the scattered muon in the laboratory frame



Model details

B. Badełek *et al.* [Phys. Rev. D 61 (1999) 014009]

(VMD contribution and QCD improved parton model extended to low Q^2)



$$g_1(x,Q^2) = g_1^{VMD}(x,Q^2) + g_1^{part}(x,Q^2). \quad (4)$$

$$g_1^{VMD}(x,Q^2) = \frac{pq}{4\pi} \sum_{v=\rho,\omega,\phi} \frac{m_v^4 \Delta\sigma_v(W^2)}{\gamma_v^2 (Q^2+m_v^2)^2}. \quad (5)$$

$$\Delta\sigma_v = \frac{\sigma_{1/2} - \sigma_{3/2}}{2}, \quad (6)$$

$$\frac{pq}{4\pi} \sum_{v=\rho,\omega} \frac{m_v^4 \Delta\sigma_v}{\gamma_v^2 (Q^2+m_v^2)^2} = C\left[\frac{4}{9}(\Delta u_v^0(x) + 2\Delta\bar{u}^0(x)) + \frac{1}{9}(\Delta d_v^0(x) + 2\Delta\bar{u}^0(x))\right] \times \frac{m_\rho^4}{(Q^2+m_\rho^2)^2}, \quad (7)$$

$$\frac{pq}{4\pi} \frac{m_\phi^4 \Delta\sigma_\phi}{\gamma_\phi^2 (Q^2+m_\phi^2)^2} = C\frac{2}{9}\Delta\bar{s}^0(x) \frac{m_\phi^4}{(Q^2+m_\phi^2)^2}, \quad (8)$$

$$\Delta p_j^0(x) = C_j (1-x)^{\eta_j}. \quad (3)$$