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

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Outline

Motivation

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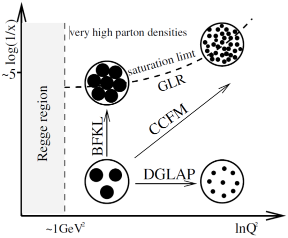
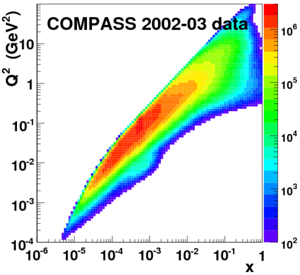
- Low x ⇔ **high parton densities**
- Fixed target experiments ⇔ **strong correlation** between x and Q^2: low x ⇒ low Q^2, where pQCD isn't expected to work
- Some **models, to be confronted with data**, allow a **smooth extrapolation to the low-$\mathbf{Q^2}$ and high-$\mathbf{Q^2}$ regions** (resummation, VDM)
- Structure function $\mathbf{g_1^{NS} = g_1^p - g_1^n}$:
  - decouples from gluons
  - predicted by models
  - can be measured with **improved precision** by COMPASS
- The results will be presented also as functions of ν, as requested by theoreticians





Definitions

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 $\mathbf{g_1(x,Q^2)}$

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)

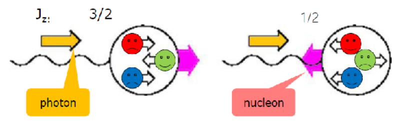
Lepton-nucleon asymmetry

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

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)

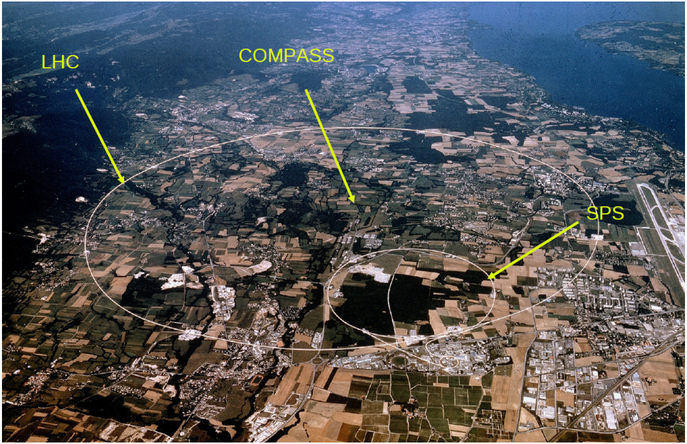
Spin dependent structure function $\mathbf{g_1}$

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

The COMPASS experiment

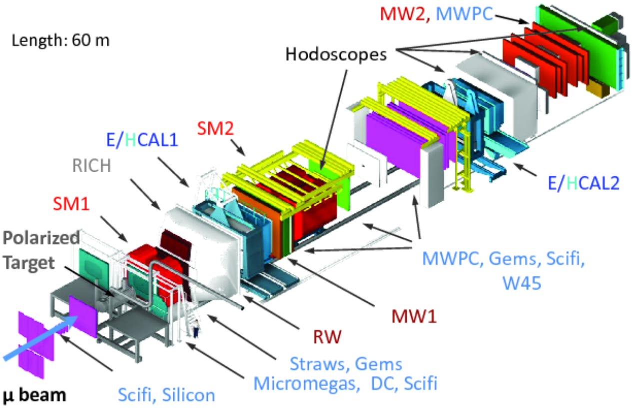
COMPASS @ CERN

[**CO**mmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy]



- **Fixed target experiment** at the SPS using a tertiary **muon beam** or a secondary **hadron beam**
- Collaboration of around 220 members from 13 countries and 24 institutions

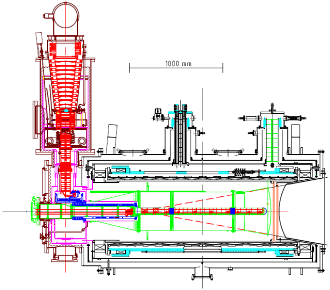
COMPASS spectrometer

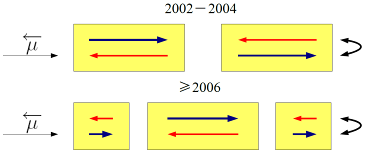


- 160/200 GeV μ^+ (or μ^-) naturally **polarised beams** or 190 GeV hadron beams (positive or negative)
- ^{6}Li**D** or N$\mathbf{H_3}$, 1.2 m long, **polarised target**

- 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): $f \sim 16\%$, $P_{\text{target}} \sim 85\%$

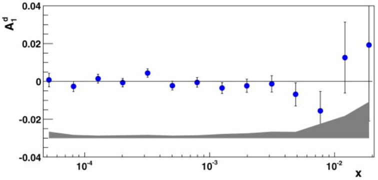
$$\mathbf{N}^{\overleftarrow{\Rightarrow},\overleftarrow{\Leftarrow}} = \mathbf{a}\phi\mathbf{n}\bar{\sigma}(\mathbf{1} \pm \mathbf{P}_{\text{beam}}\mathbf{P}_{\text{target}}\mathbf{fDA}_{||})$$

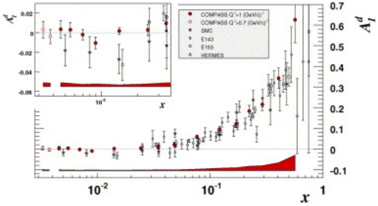
Cancellation of $a\phi n\bar{\sigma}$ via:

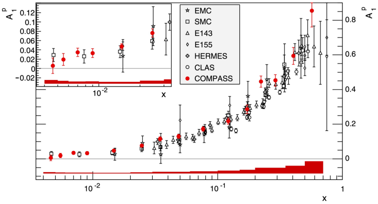
- **flux cancellation**
  - beam or extrapolation must cross all the target cells
- **acceptance cancellation**
  - 3 target cells
  - polarisation rotation every 24 hours
  - grouping of runs in ∼48 h long configurations
  - reversal of "microwave setting" at least once per year

Previous COMPASS results

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

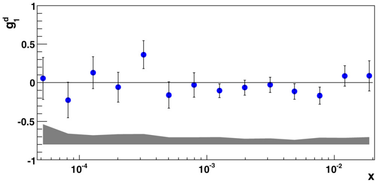
<table>
<tr><th></th><th>$\mathbf{Q^2 < 1\ (GeV/c)^2}$</th><th>$\mathbf{Q^2 > 1\ (GeV/c)^2}$</th></tr>
<tr><td>$\mathbf{A_1^d}$</td><td>


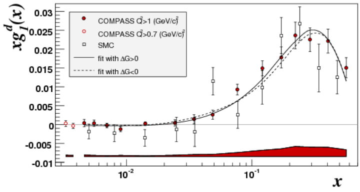
[COMPASS, PLB 647 (2007) 330]</td><td>


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


[COMPASS, PLB 690 (2010) 466]
↪ more in A. Ivanov's talk</td></tr>
</table>

COMPASS published $g_1^{p,d}$ data

<table>
<tr><th></th><th>$Q^2 < 1\ (GeV/c)^2$</th><th>$Q^2 > 1\ (GeV/c)^2$</th></tr>
<tr><td>g_1^d</td><td>

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

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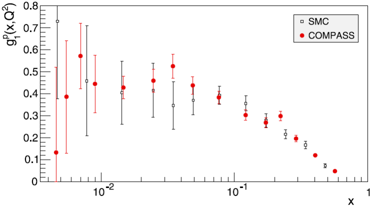
<tr><td>g_1^p</td><td></td><td>

[COMPASS, PLB 690 (2010) 466]
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</table>

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

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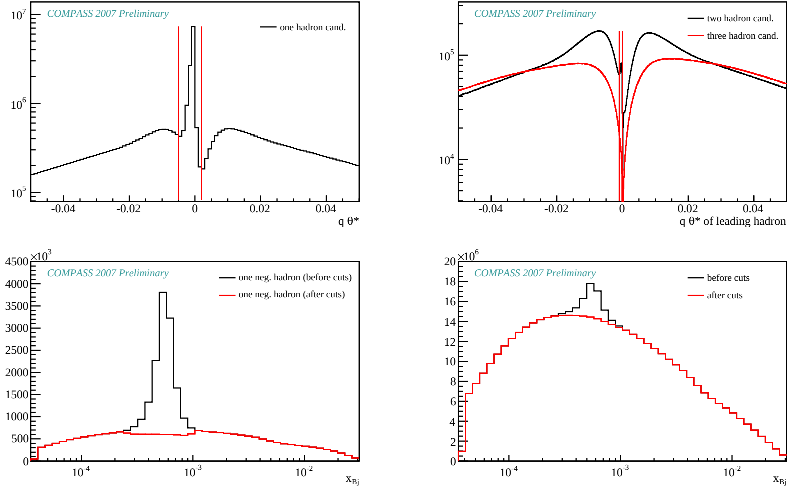
- Longitudinally polarised target (NH_3): **676×10^6 events**
  (447×10^6 with 160 GeV beam in 2007, 229×10^6 with 200 GeV beam in 2011)

- 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")
- not a μe elastic scattering event
- $Q^2 < 1$ $(\text{GeV}/c)^2$
- $x \geq 4 \times 10^{-5}$
- $0.1 < y < 0.9$

Removal of μe elastic scattering events for 2007 data

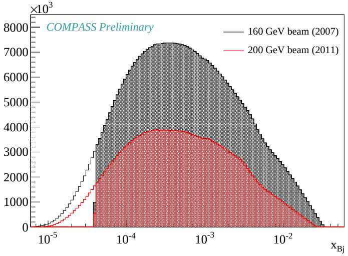


$q\theta^*$: charge $\times$ angle of the track with respect to the virtual photon direction

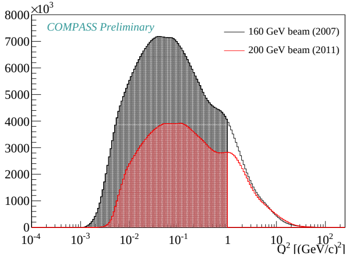
The cut effectively eliminates the μe events from the sample.

Kinematic variables of the final samples

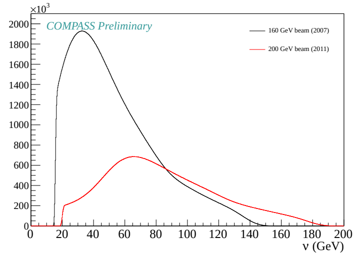
x



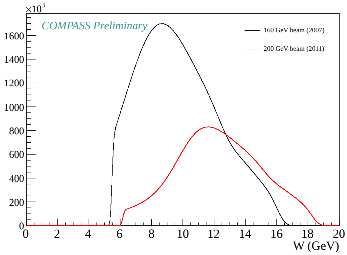
Q^2 $(\mathrm{GeV}/c)^2$



ν (GeV)

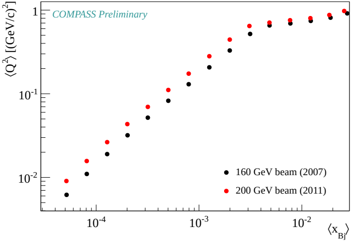


W (GeV)

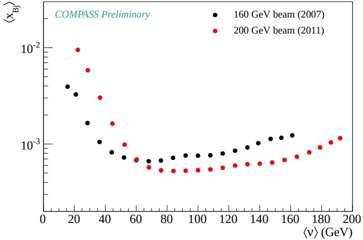


Features of the final samples

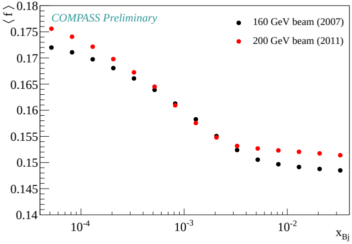
$\langle Q^2 \rangle$ $(\text{GeV}/c)^2$ vs $\langle x \rangle$



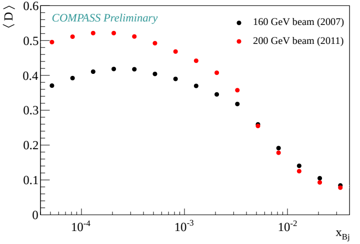
$\langle x \rangle$ vs $\langle \nu \rangle$ (GeV)



$\langle f \rangle$ vs x



$\langle D \rangle$ vs x

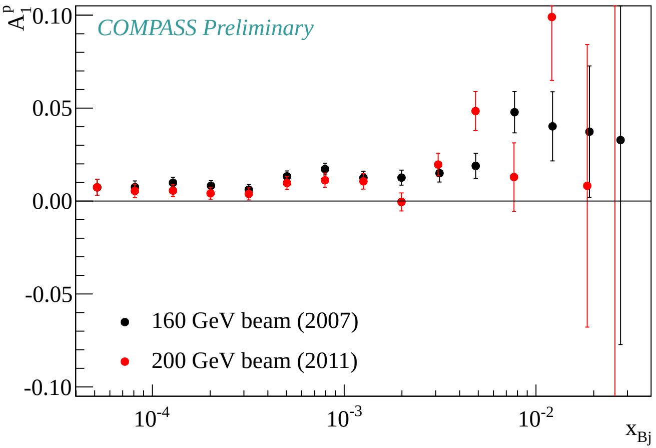


Double spin longitudinal asymmetry A_1^p

Double spin longitudinal asymmetry A_1^p

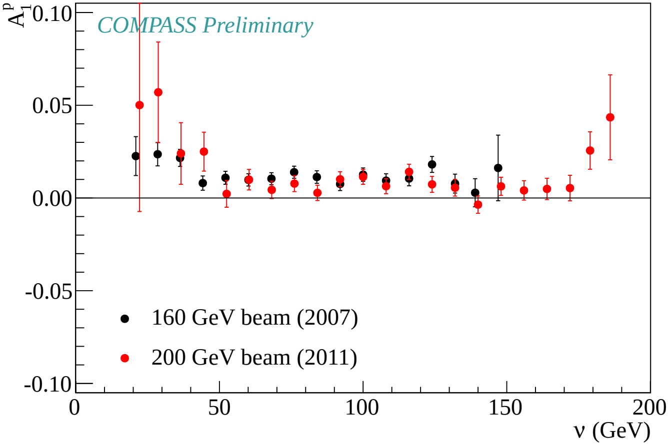
- Obtained giving each event a weight $\omega = \mathbf{fD}|\mathbf{P_b}|$ ($\hookrightarrow$ details in A. Ivanov's talk)
- Unpolarised radiative corrections (RC), included in the dilution factor, from TERAD
- Polarised radiative corrections ($A^{\mathrm{RC}} \leq 0.25\,\delta A_1^{\mathrm{stat}}$) from POLRAD
- 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 (which dominate the systematic error) $\Rightarrow$ systematic errors are smaller than the statistical errors

New results for A_1^p as a function of x



The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors.
The asymmetries are mostly **incompatible with zero and positive**.

New results for A_1^p as a function of ν



The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors.
The asymmetries are mostly **incompatible with zero and positive**.
No special dependence with ν is observed.

Spin dependent structure function g_1^p

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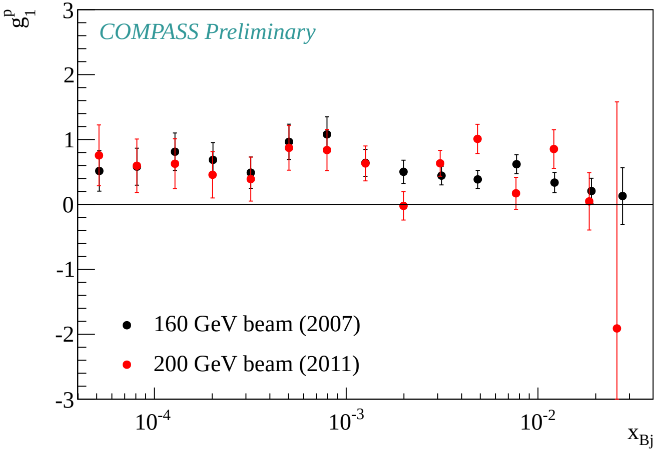
- The structure function is obtained in bins of x or ν according to:

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

- $\mathbf{F_2^p}(\langle \mathbf{x} \rangle, \langle \mathbf{Q^2} \rangle)$ 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]

- $\mathbf{R}(\langle \mathbf{x} \rangle, \langle \mathbf{Q^2} \rangle)$ from data or from a parameterisation (for low x)
  [COMPASS, PLB 647 (2007) 330]

New results for g_1^p as a function of x



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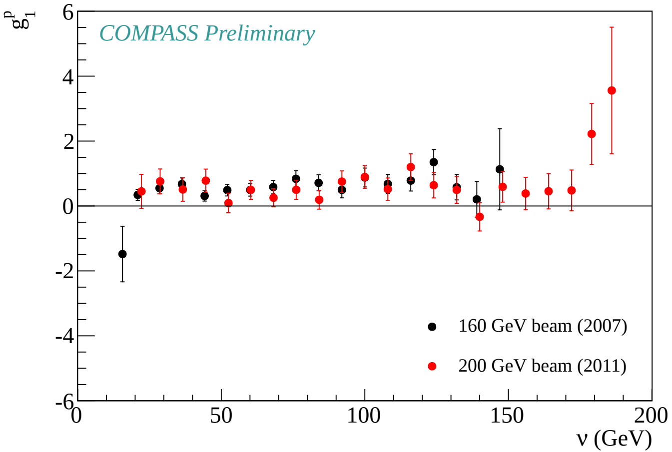
New results for g_1^p as a function of ν



The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors.
g_1^p is mostly **incompatible with zero and positive**.
No special dependence with ν is observed.

Summary and outlook

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Done

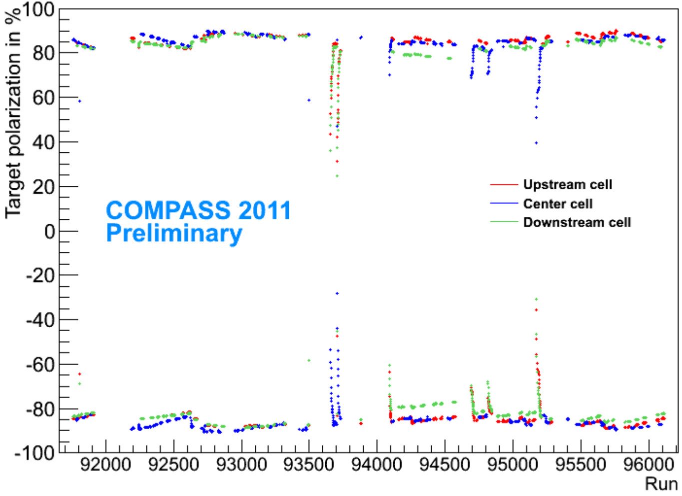
- A_1^p and g_1^p measured for $0.001 < Q^2 < 1\ (\mathrm{GeV}/c)^2$, $4 \times 10^{-5} < x < 4 \times 10^{-2}$, and $14 < \nu < 194$ GeV, in bins of x or in bins of ν
- Total statistics **150 times larger** than SMC
- Results from data at 160 GeV and 200 GeV are compatible
- Results of A_1^p and g_1^p are **incompatible with zero and positive**

Next

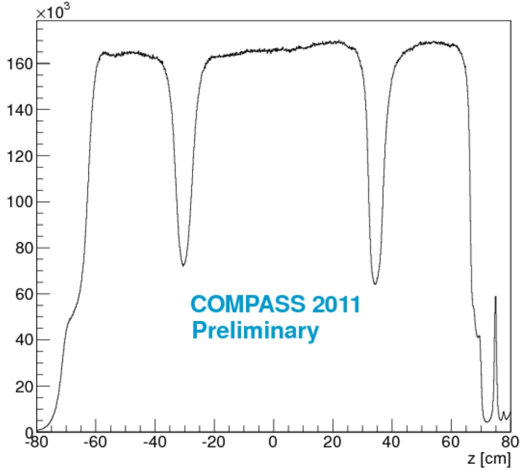
- Obtain $\mathbf{g_1^{NS}}$ from g_1^p and g_1^d. Fit data to models.
- Extract asymmetries and g_1^p in **2D bins**, *e.g.* (x, Q^2). Extract A_1^d and g_1^d from the full COMPASS deuteron data (2002-2006) in bins of ν.

BACKUP

Target polarisation in 2011

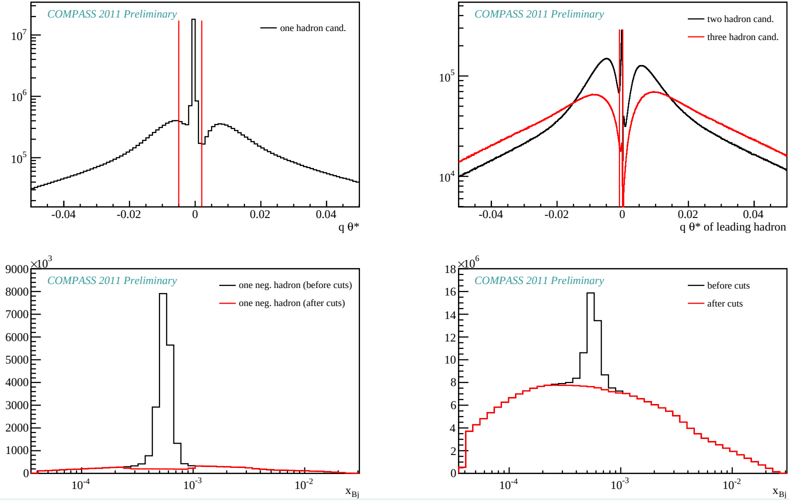


Z position of the primary vertices (DIS sample)



(The cut on Z_{PV} is missing.)

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