

The structure function g_1 measured at COMPASS

Vincent Andrieux

Irfu/SPhN CEA-Saclay
COMPASS

6. December 2012

GdR Nucleon

- ① Inclusive Deep Inelastic Scattering
- ② Semi-inclusive Deep Inelastic Scattering
- ③ Compass Spectrometer
- ④ Results
- ⑤ Conclusions and perspectives

What is the nucleon spin made up of?

Proton structure

- 3 valence quarks : uud
- gluons
- sea quarks
 $(u_{sea}, d_{sea}, s, \bar{u}, \bar{d}, \bar{s})$

Spin contribution

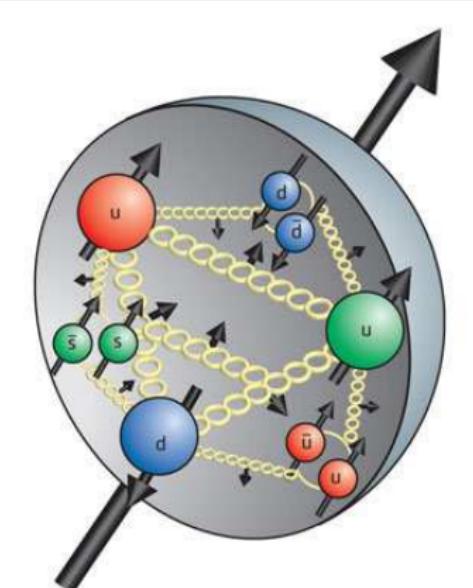
Spin sum rule :

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_g + L_q \text{ where}$$

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$

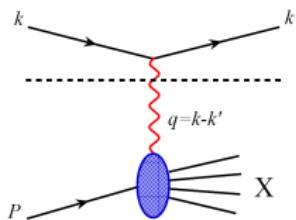
$$\Delta q = \int (q(x)^+ - q(x)^-) dx$$

artist's view



Inclusive deep inelastic scattering : Access to g_1

DIS process



Kinematic variables

$$Q^2 = -q^2 = -(k-k')^2$$

$$x_{Bj} = \frac{Q^2}{2M_P\nu}$$

virtuality of the photon

Bjorken variable

Inclusive cross section

$$\frac{d^2\sigma}{dx_{Bj} dQ^2} = \underbrace{c_1 F_1(x_{Bj}, Q^2) + c_2 F_2(x_{Bj}, Q^2)}_{unpolarised\ structure\ function} + \underbrace{c_3 g_1(x_{Bj}, Q^2) + c_4 g_2(x_{Bj}, Q^2)}_{polarised\ structure\ function}$$

Parton model

$$F_1(x_{Bj}, Q^2) = \frac{1}{2} \sum_q e_q^2 q(x_{Bj})$$

$$F_2(x_{Bj}, Q^2) = 2 x_{Bj} \sum_q e_q^2 q(x_{Bj})$$

$$g_1(x_{Bj}, Q^2) = \frac{1}{2} \sum_q e_q^2 \Delta q(x_{Bj})$$

$$g_2(x_{Bj}, Q^2) = 0$$

Structure functions do not depend on Q^2 in the naive parton model

g_1 extraction from double spin asymmetry

Double spin asymmetry

$$A_{||} = \frac{d\sigma^{\rightarrow\rightarrow} - d\sigma^{\rightarrow\leftarrow}}{d\sigma^{\rightarrow\rightarrow} + d\sigma^{\rightarrow\leftarrow}} = D(A_1 + \eta A_2)$$

where D and η are kinematic variables.

COMPASS case : $\eta \propto \frac{x}{Q} \sim 0$

Virtual photon-nucleon asymmetry

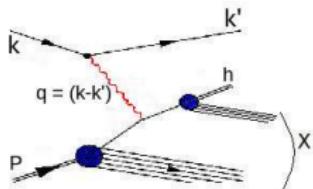
$$A_1 = \frac{g_1 - \gamma^2 g_2}{F_1} \sim \frac{g_1}{F_1} \qquad \qquad A_2 = \gamma \frac{g_1 + g_2}{F_1} \sim 0$$

where $\gamma^2 = \frac{4M^2x^2}{Q^2}$ is a kinematic variable (small at COMPASS)

$$\Rightarrow A_{||} \approx D \left(\frac{g_1}{F_1} \right)$$

Semi-inclusive deep inelastic scattering

SIDIS process



Kinematic variables

$$z = \frac{E_\mu - E_h}{E_\mu} \quad \text{fraction of energy transferred to the hadron}$$

Semi-Inclusive asymmetry

$$A_1^h(x_{Bj}, z) = \frac{\sum_q e_q^2 \Delta q(x_{Bj}) D_q^h(z)}{\sum_q e_q^2 q(x_{Bj}) D_q^h(z)}$$

Fragmentation functions

D_q^h : probability for a parton q to hadronize into a hadron h , universal quantity

Outgoing hadron tags the quark flavour → access to polarised quark distribution per flavour

Outgoing hadron ($\pi^{+/-}$ and $K^{+/-}$) identification (RICH detector)

Motivation for polarised (SI)DIS at high energy

Why another year of data taking ?

polarised target	year	statistics (in 10^6 DIS events)
${}^6\text{LiD}$ (deuteron)	2002-2006 @ 160 GeV	135.1
NH_3	2007 @ 160 GeV 2011 @ 200 GeV	85.3 77.9

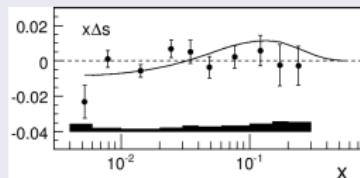
Balance data between proton and deuteron

- Bjorken sum rule :

$$\begin{aligned}\rightarrow \int g^{NS} dx &= \int g^p - g^n dx = \frac{1}{6} \frac{|g_A|}{|g_V|} C^{NS} \\ \Rightarrow \frac{|g_A|}{|g_V|} &= 1.28 \pm 0.07(\text{stat}) \pm 0.1(\text{syst})\end{aligned}$$

- Flavors separation :

$\rightarrow \Delta s, \Delta \bar{s}, \Delta \bar{u}, \Delta \bar{d}$ poorly known at low x



Why another year of data taking ?

Extend data range to lower x and higher Q^2

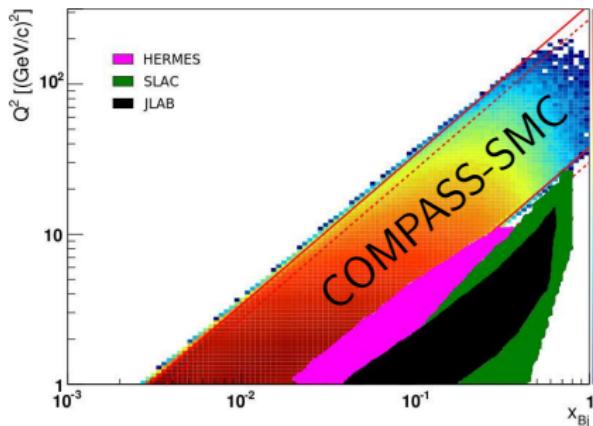
- $\int g_1^p(x, Q^2) dx =$
$$\underbrace{(\Delta u - \Delta d)/12}_{\text{neutron } \beta \text{ decay}} + \underbrace{(\Delta u + \Delta d - 2\Delta s)/36}_{\text{hyperon } \beta \text{ decay}} + \underbrace{(\Delta u + \Delta d + \Delta s)/9}_{\Delta\Sigma}$$

- large contribution of $g_1^p(x, Q^2)$ at low x while the less known
- Indirect access to ΔG via $g_1(x, Q^2)$ evolution
- wide (x, Q^2) domain needed

Phase-space

Kinematic domain covered by COMPASS compared to other experiments

- $0.0025 \leq x_{Bj} \leq 0.7$
- $1 \text{ GeV}^2 \leq Q^2 \leq 120 \text{ GeV}^2$

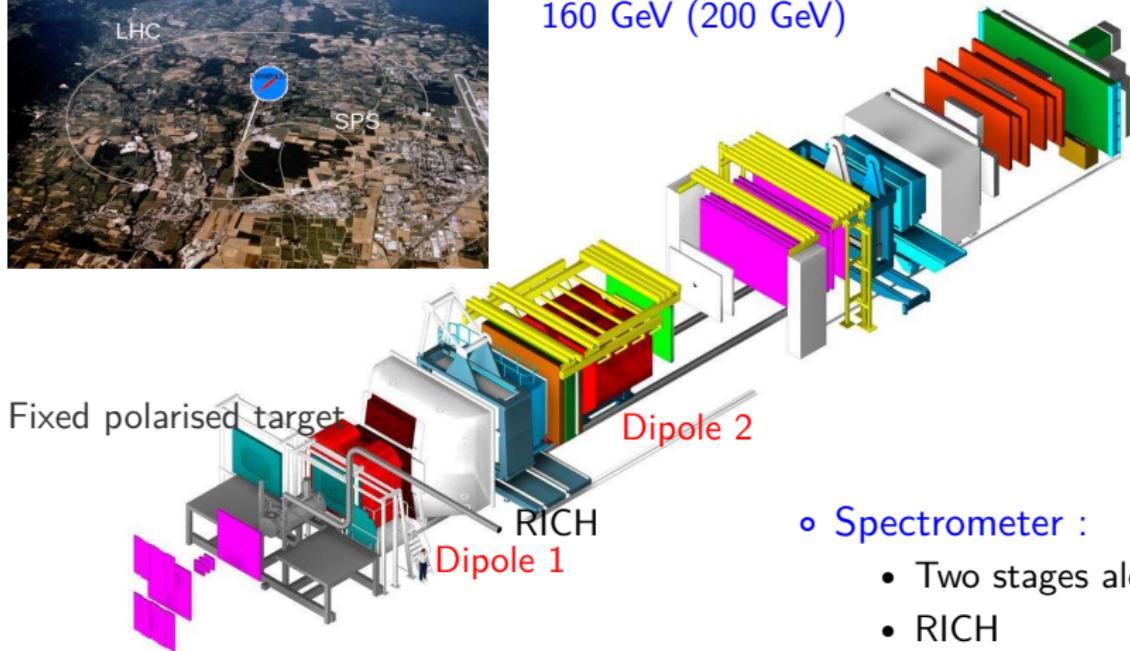


→ COMPASS is the only experiment to reach $x_{Bj} \sim 10^{-3}$ in polarised SIDIS

COMPASS Spectrometer



Secondary polarized μ beam from SPS
160 GeV (200 GeV)



- Spectrometer :
 - Two stages along 60 m
 - RICH

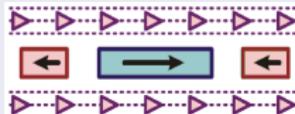
From Counting to Asymmetry extraction

Asymmetry extraction at COMPASS

$$\frac{A_{\parallel}}{D} = \frac{1}{|P_B P_T| f D} \frac{1}{2} \left(\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \right)$$

Simultaneous recording of the two spin states in oppositely polarised target cells

COMPASS target



- Reversal by field rotation every 24h to cancel out acceptance difference
- Reversal by micro-wave once in a while to cancel out acceptance/field correlation

From Counting to Asymmetry extraction

Asymmetry extraction at COMPASS

$$\frac{A_{\parallel}}{D} = \frac{1}{|P_B P_T| f D} \frac{1}{2} \left(\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \right)$$

Simultaneous recording of the two spin states in oppositely polarised target cells

COMPASS target



- Reversal by field rotation every 24h to cancel out acceptance difference
- Reversal by micro-wave once in a while to cancel out acceptance/field correlation

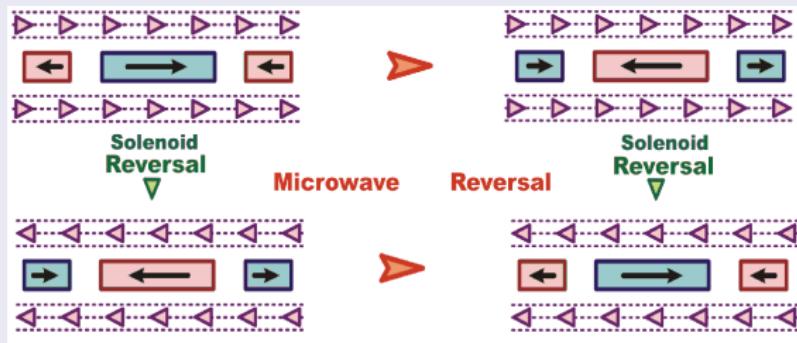
From Counting to Asymmetry extraction

Asymmetry extraction at COMPASS

$$\frac{A_{\parallel}}{D} = \frac{1}{|P_B P_T| f D} \frac{1}{2} \left(\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \right)$$

Simultaneous recording of the two spin states in oppositely polarised target cells

COMPASS target



- Reversal by field rotation every 24h to cancel out acceptance difference
- Reversal by micro-wave once in a while to cancel out acceptance/field correlation



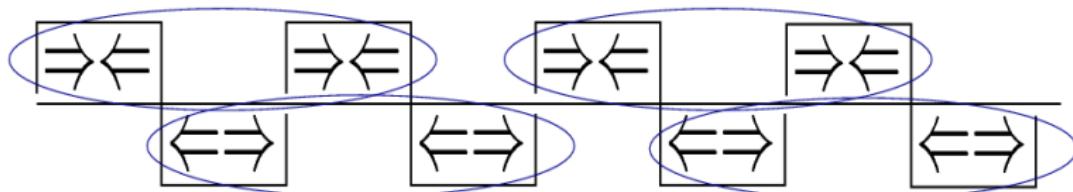
Study of systematics

Measurement of small quantities : $A(x)$ down to a few percents

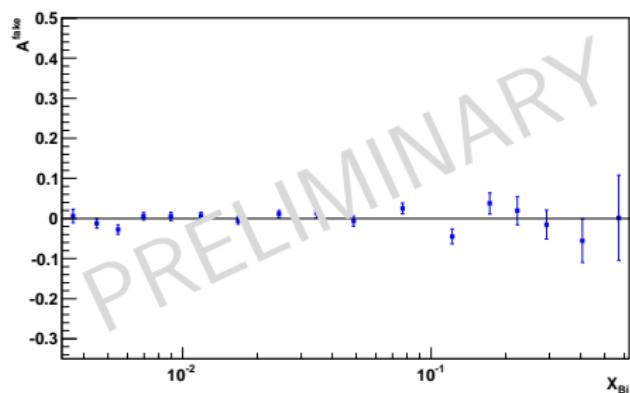
→ Carefull studies of systematics

- **Fake spin configuration association**
- Microwave reversal
- Solenoid reversal
- Day-night asymmetry
- Different part of the cells asymmetry
- **Stability over time (~ 5 months of data taking)**

Fake spin configuration association

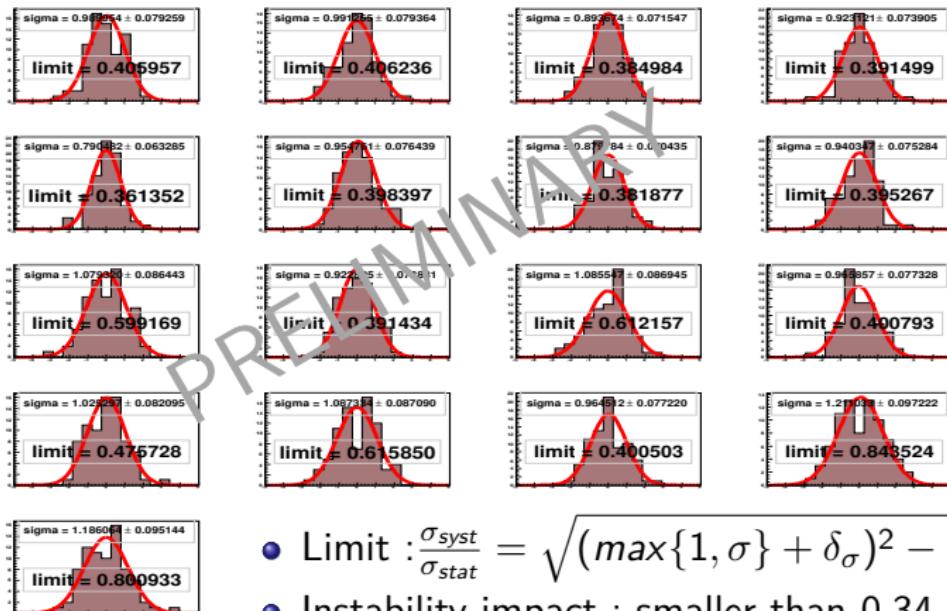


- Combining runs with the same spin configuration
- Physical asymmetry must be zero
- $\chi^2/N_{\text{df}} \sim 23.5/16$ (10%)
→ Reasonably compatible with zero



Stability over time

- 1 pull distribution per x-bin
- 1 entry $\sim 48\text{h}$ of data with 1 field rotation



- Limit : $\frac{\sigma_{\text{syst}}}{\sigma_{\text{stat}}} = \sqrt{(\max\{1, \sigma\} + \delta_\sigma)^2 - 1}$
- Instability impact : smaller than 0.34 to 0.84 \times the statistical error

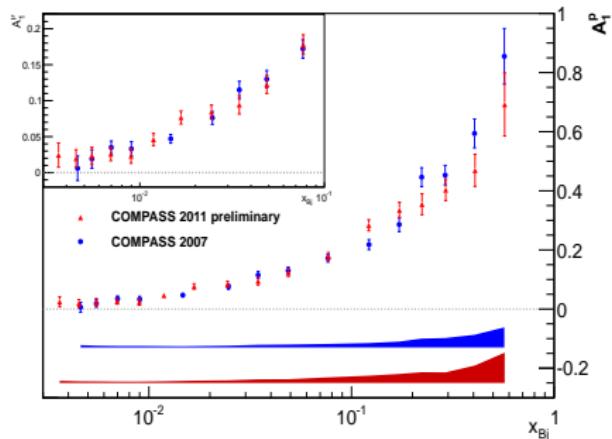
Systematic error

- Two kinds of contributions :
 - Multiplicative
 - Additive

$$A_1^{1\gamma} = \frac{1}{fDP_B P_T} A^{\text{raw}} - \left(\frac{\eta A_2}{\rho} + A_1^{\text{RC}} + A_{\text{pulls}} \right)$$

Multiplicative variables error, ΔA_1^{mult}	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	$\Delta A_1^{\text{mult}} \simeq 0.08 A_1$	
Additive variables error, ΔA_1^{add}	Transverse asymmetry	$\eta / \rho \cdot \Delta A_2$	$10^{-3} - 10^{-2}$
	Rad. corrections	ΔA_1^{RC}	$0.1 \cdot \text{Max}(A_{1, \text{incl}}^{\text{RC}} , A_{1, \text{hadr}}^{\text{RC}}) = 10^{-5} - 10^{-3}$
	pull distributions	A_{pulls}	$< 0.34 : 0.84 \cdot \Delta A_1^{\text{stat}} \text{ (Dominant)}$

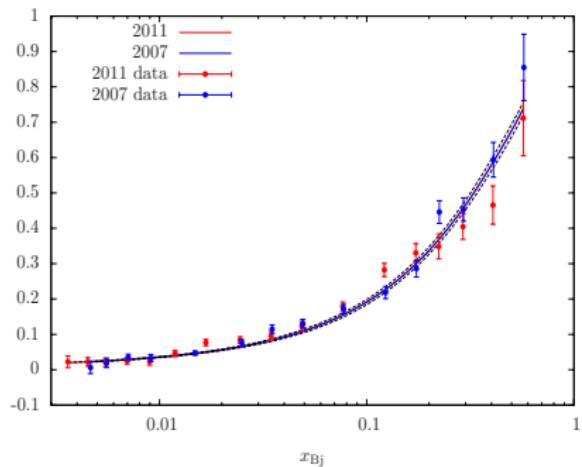
Proton Asymmetry : 2011 at 200 GeV with 2007 at 160 GeV results



- Comparison via a parametrisation for A_{1p} (S. Kuhn) to take into account any Q^2 dependence
- The parametrisation at the two Q^2 is indistinguishable

$\chi^2/Ndf(\text{probability})$				
	2007		2011	
	only stat. err.	stat. + syst. err.	only stat. err.	stat. + syst. err.
all pts.	21.0/15 (13.8%)	13.4/15 (57.4%)	35.6/17 (0.5%)	18.4/17 (36.7%)
$x > 0.1$	7.4/6 (28.5%)	4.3/6 (63.3%)	15.9/6 (1.4%)	7.2/6 (30.6%)
$x < 0.1$	13.6/9 (13.9%)	9.0/9 (43.3%)	19.7/11 (5.0%)	11.2/11 (42.7%)

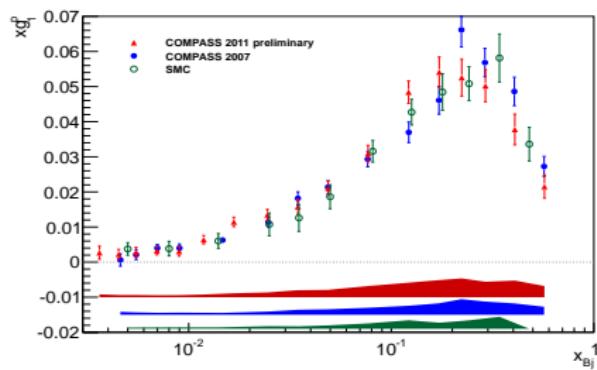
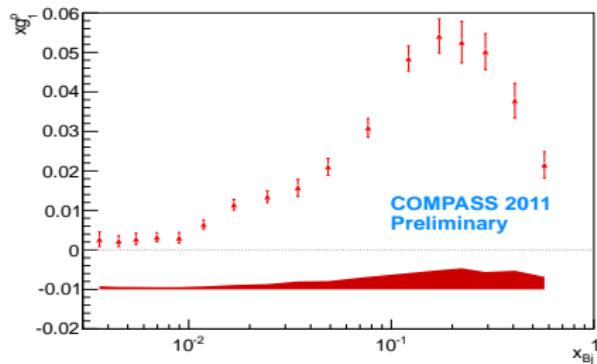
Proton Asymmetry : 2011 at 200 GeV with 2007 at 160 GeV results



- Comparison via a parametrisation for A_{1p} (S. Kuhn) to take into account any Q^2 dependence
- The parametrisation at the two Q^2 is indistinguishable

	$\chi^2/Ndf(\text{probability})$			
	2007		2011	
	only stat. err.	stat. + syst. err.	only stat. err.	stat. + syst. err.
all pts.	21.0/15 (13.8%)	13.4/15 (57.4%)	35.6/17 (0.5%)	18.4/17 (36.7%)
$x > 0.1$	7.4/6 (28.5%)	4.3/6 (63.3%)	15.9/6 (1.4%)	7.2/6 (30.6%)
$x < 0.1$	13.6/9 (13.9%)	9.0/9 (43.3%)	19.7/11 (5.0%)	11.2/11 (42.7%)

The structure function of the proton xg_1^p

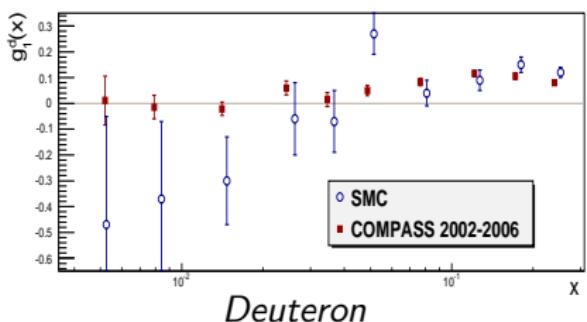
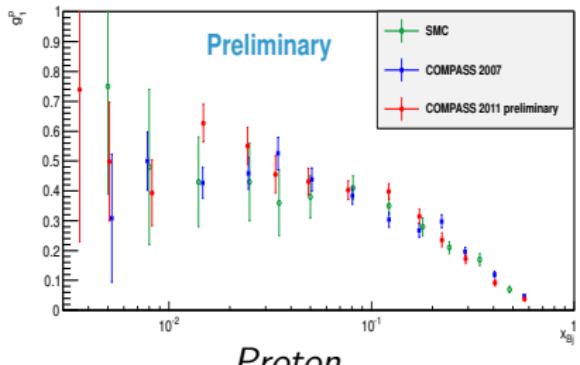


- Calculation of g_1 :

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

- NMC parametrisation of F_2
- R stands for $\frac{\sigma^L}{\sigma^T}$ (C. Keppel)
- Good agreement between the data \rightarrow gain in precision

The structure function



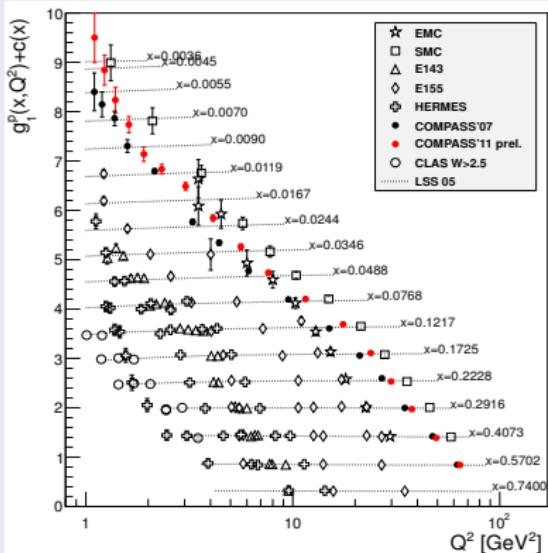
- Calculation of g_1 :

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

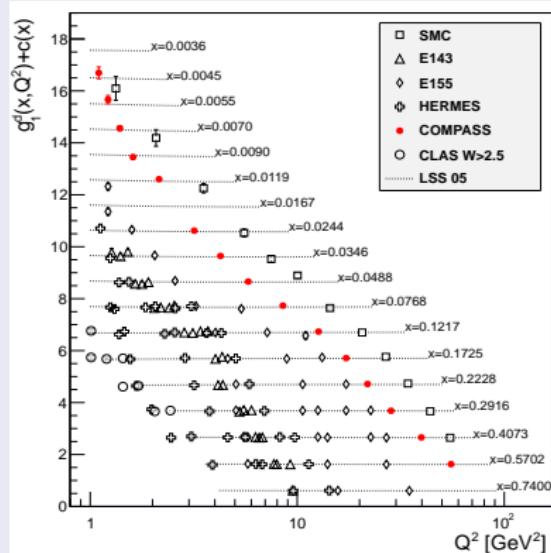
- NMC parametrisation of F_2
- R stands for $\frac{\sigma^L}{\sigma^T}$ (C. Keppel)
- Comparable statistics between p and d

g_1 evolution

Proton



Deuteron



- $g_1^p(x)$ and $g_1^d(x)$ as a function of $\langle Q^2 \rangle$ for the different x bins
- NEW data point at very low x for the proton
Future : split of data in Q^2 bins for $x > 0.02$

Conclusions and perspectives

- Improve of statistics
- Extra low x_{Bj} measured point
- g_1 at compass wider kinematic domain
- Next to do :
 - Compute the asymmetry in x_{Bj} and Q^2 bins : $A_1^p(x_{Bj}, Q^2)$ for a global QCD analysis
 - Measure identified hadron asymmetry : $A_{1,p}^{\pi^+}$, $A_{1,p}^{\pi^-}$, $A_{1,p}^{K^+}$ and $A_{1,p}^{K^-}$ and extract $\Delta q(x)$

COMPASS timelines

2012 Pion polarisabilities + DVCS

2013 CERN Long Shut Down

2014 "

2015 "

2016 "

TMDs via Polarized Drell-Yan

DVCS

DVCS

+ Hadron spectroscopy

Future: Polarized GPDs, polarized SIDIS,
polarized Drell-Yan...

2012 DVCS data taking

With final LH2 target and recoil proton detector

