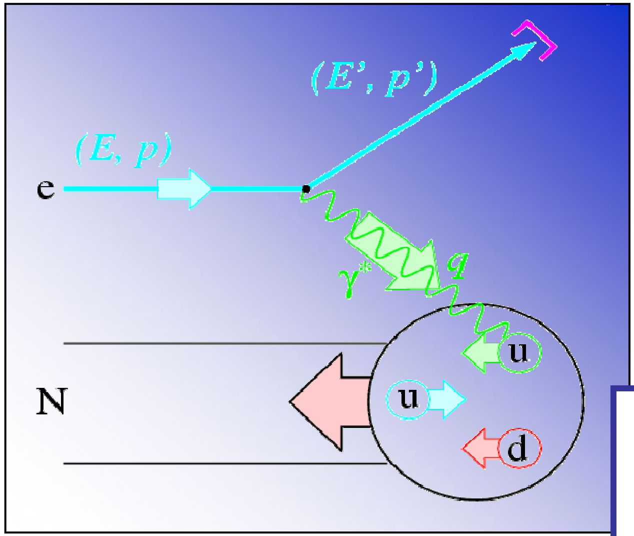
Measurement of the spin structure functions g_1^p and g_1^d at HERMES

Lara De Nardo

TRIUMF/DESY

Inclusive Deep Inelastic Scattering



$$\frac{\partial^2 \sigma}{\partial \Omega \partial E'} \propto L_{\mu\nu} W^{\mu\nu}$$

$$g_1 \approx \langle e^2 \rangle \left[\Delta C_\Sigma \otimes \Delta\Sigma + \Delta C_G \otimes \Delta G + \Delta C_{NS} \otimes \Delta q_{NS}^{p,n} \right]$$

$$= \frac{1}{2} \langle e^2 \rangle \left[\Delta\Sigma + \Delta q_{NS}^{p,n} \right] \quad \textit{in}\ \text{LO QCD}$$

$L_{\mu\nu}$ *is exact in* QED

$$\mathbf{W}^{\mu\nu} = -g^{\mu\nu}\mathbf{F_1} + \frac{p^\mu p^\nu}{\nu}\mathbf{F_2} + \frac{i}{\nu}\epsilon^{\mu\nu\lambda\sigma}q^\lambda s^\sigma \mathbf{g_1} + \frac{i}{\nu^2}\varepsilon^{\mu\nu\lambda\sigma}q^\lambda(p\cdot q s^\sigma - s\cdot q p^\sigma)\mathbf{g_2}$$

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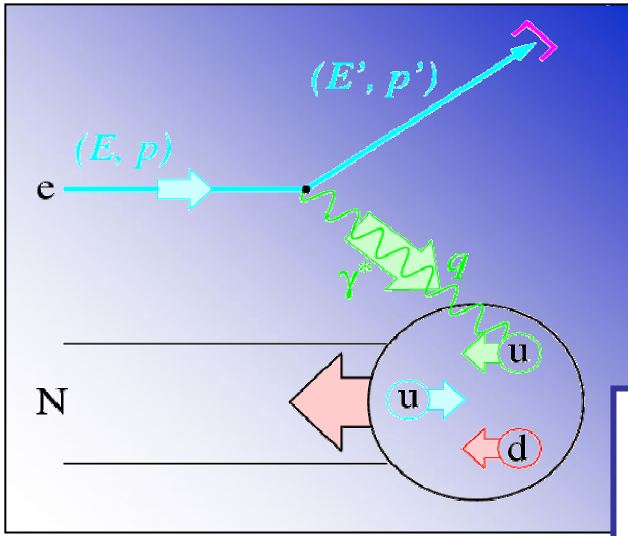

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Measured Inclusive Asymetries

P_{zz}=0.83±0.03

A_{zz}~0.01

$$\frac{b_1^d}{F_1^d} = -\frac{3}{2} A_{zz}$$

$$\sigma = \sigma_{unpol}[1 + P_B P_z A_{||} + \underbrace{\frac{1}{2} P_{zz} A_{zz}}_{\mathbf{d}}]$$

measured DIS cross section

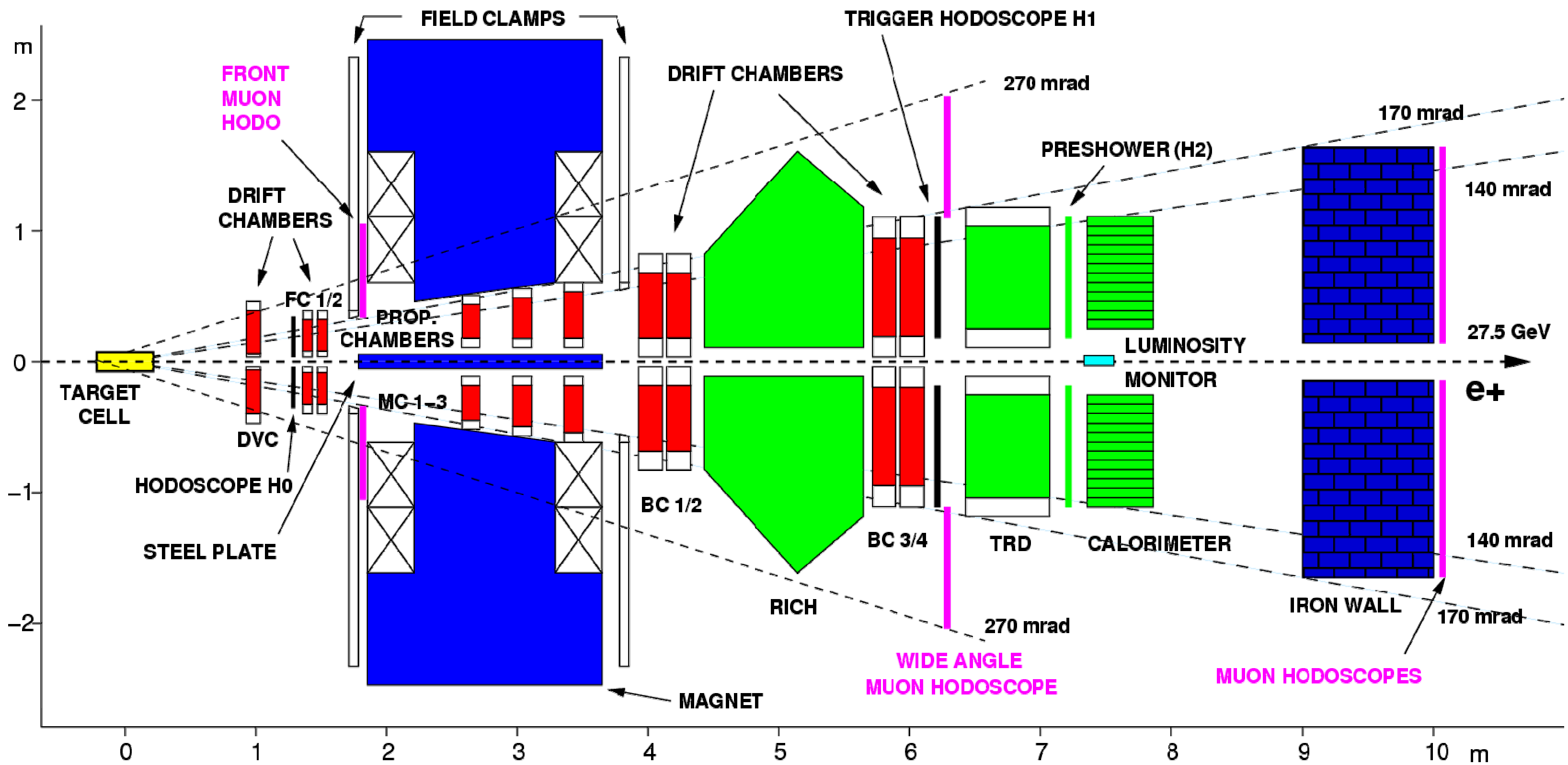
inclusive asymmetry:

$$A_{||} = \frac{\sigma^{\overleftarrow{\Leftarrow}} - \sigma^{\overleftarrow{\Rightarrow}}}{\sigma^{\overleftarrow{\Leftarrow}} + \sigma^{\overleftarrow{\Rightarrow}}} = \frac{1}{P_B P_z} \cdot \frac{\frac{N^{\overleftarrow{\Leftarrow}}}{L^{\overleftarrow{\Rightarrow}}} - \frac{N^{\overleftarrow{\Rightarrow}}}{L^{\overleftarrow{\Leftarrow}}}}{\frac{N^{\overleftarrow{\Leftarrow}}}{L^{\overleftarrow{\Rightarrow}}} + \frac{N^{\overleftarrow{\Rightarrow}}}{L^{\overleftarrow{\Leftarrow}}}}$$

$$g_1(x,Q^2) = \frac{1}{1 - \frac{y}{2} - \frac{1}{4} y^2 \gamma} \left[\frac{Q^4}{8\pi\alpha^2 y} \frac{\partial^2 \sigma_{unpol}}{\partial x \partial Q^2} A_{||}(x,Q^2) + \frac{y}{2} \gamma^2 g_2(x,Q^2) \right]$$

kinematic factors *param.* *measured* *kin. fact.* *param.*

The HERMES Spectrometer



Reconstruction: $\delta p/p < 2\%$, $\delta\theta < 1$ mrad

Internal Gas Target: unpol: H_2, D_2, He, N, Ne, Kr, Xe , He , H , D , H

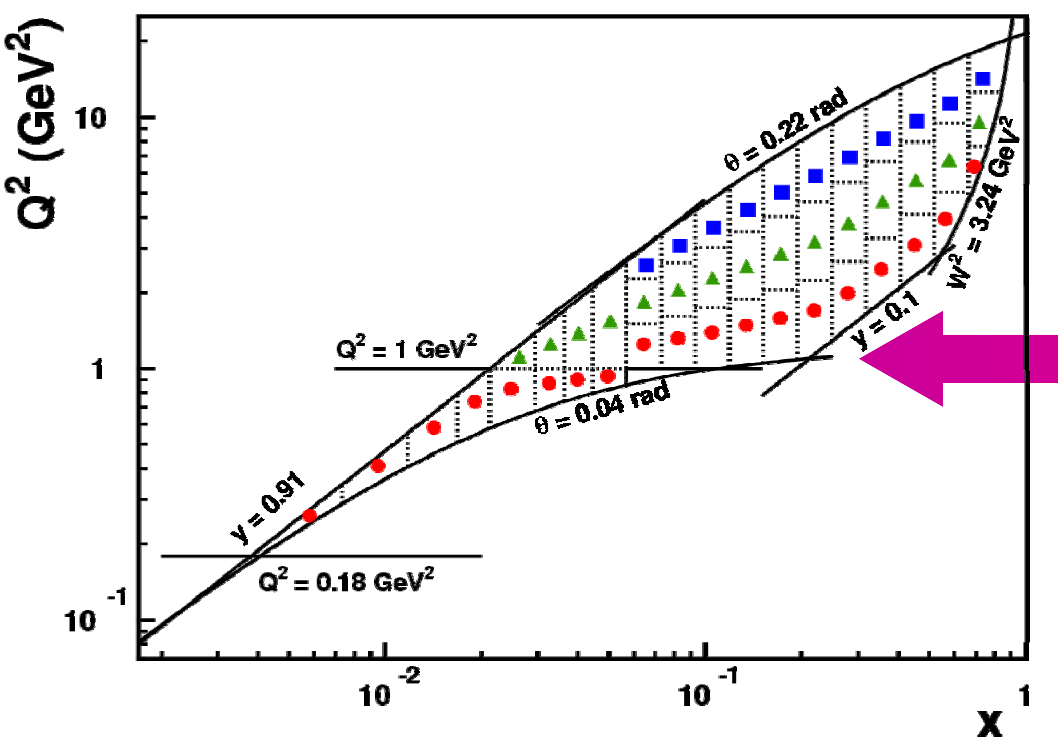
Particle ID: TRD, Preshower, Calorimeter --- 1997: Cherenkov, 1998: RICH

The data

Target	Year	Luminosity (pb^{-1})	#	P_{target} (%)
H	1996	12.6	670,000	75.9 ± 3.2
H	1997	37.3	2,800,000	85.1 ± 3.2
D	2000	138.7	10,900,000	85.1 ± 3.2 (+) 84.0 ± 3.1 (-)

P_{beam}~(53±1.8)%

P_{beam}~(53±1.0)%

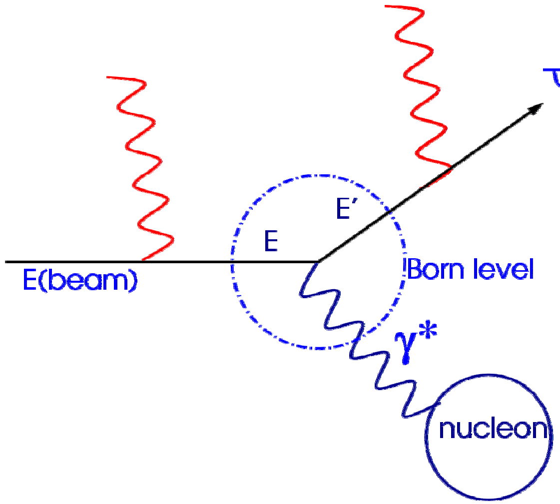


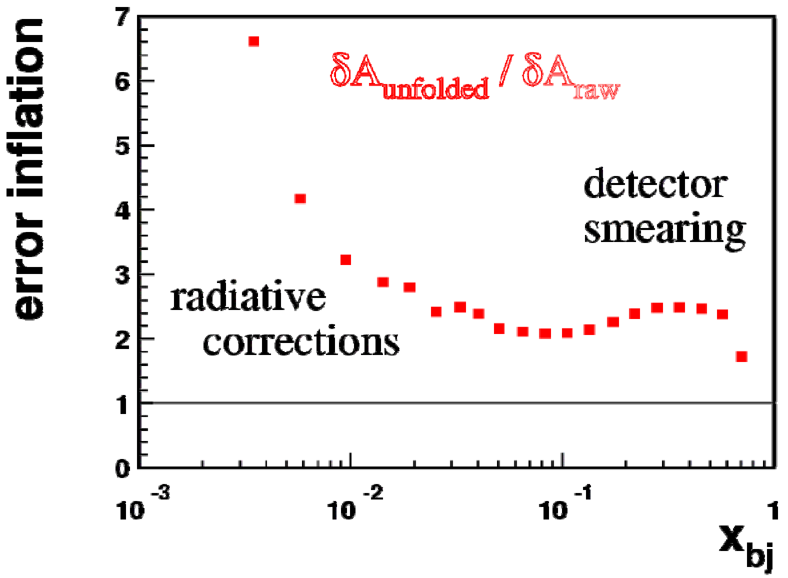
*Full analysis published in Phys.Rev.**D75** (2007)012007*

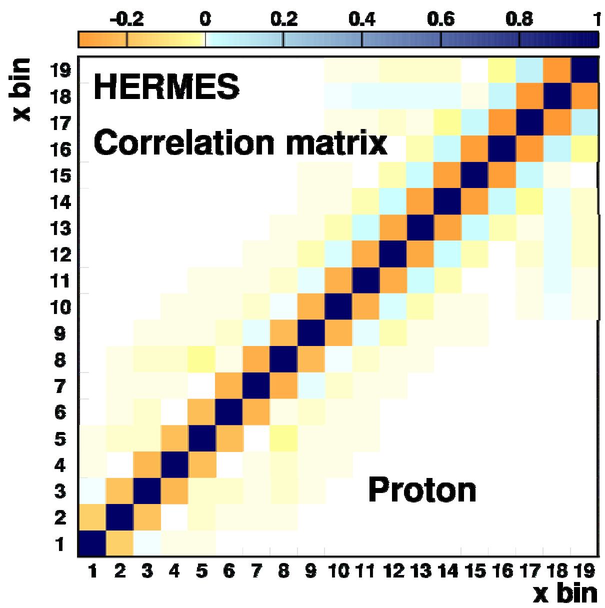
The cut at Q^2=1GeV^2 identifies the DIS region

Unfolding of radiative corrections

- *Measured events have to be corrected for:*
  - *Background tail (radiation from (quasi)-elastic)*
  - *Radiation from DIS and detector smearing*
- *The smearing of events is simulated through a MonteCarlo which includes a full detector description and a model for the cross-section*
- *The approach is independent on the model for the asymmetry in the measured region*

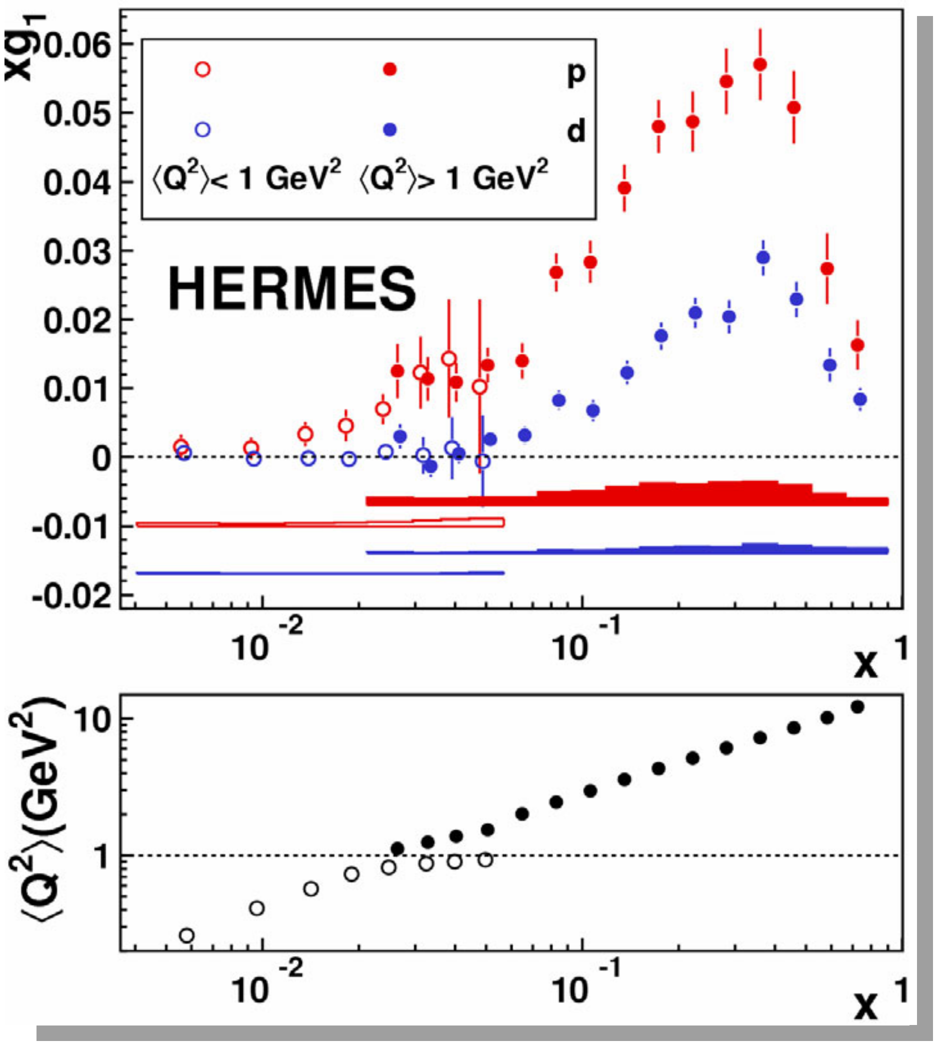


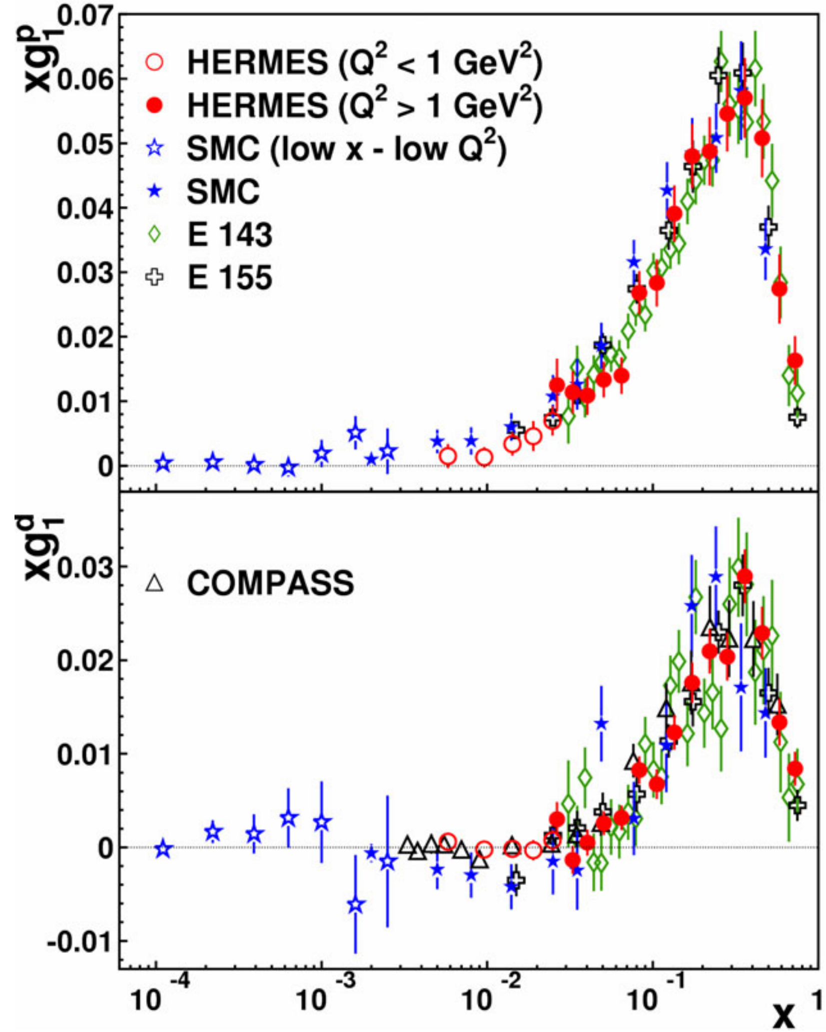




The correction for the systematic effect introduces statistical correlations

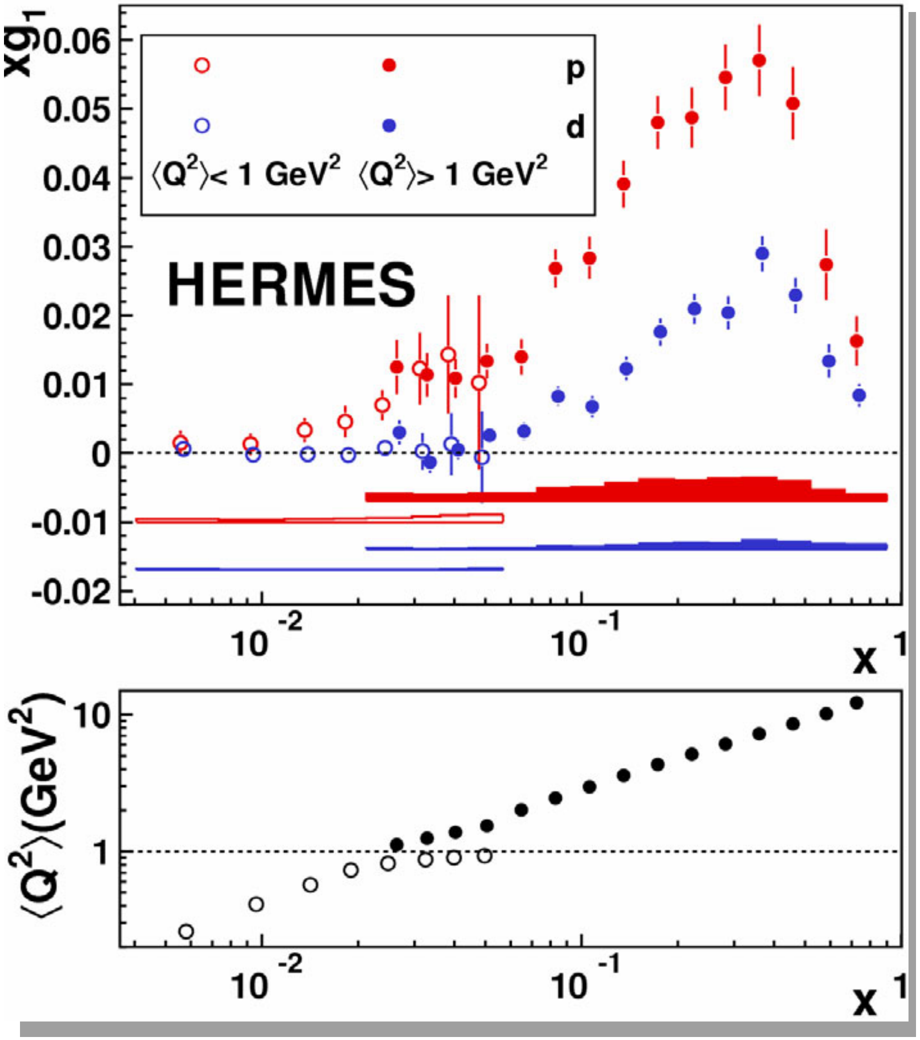
g_1 results

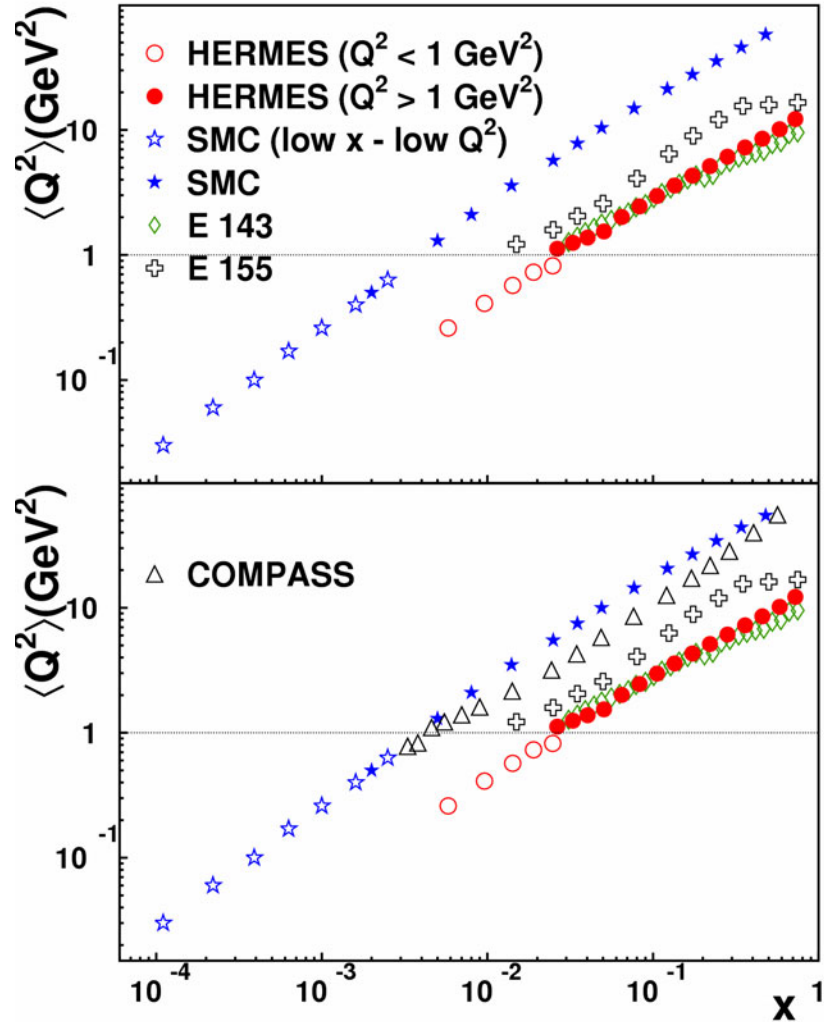




- *Statistical uncertainties are diagonal elements of covariance matrix*
- *Systematic unc. are dominted by target and beam* polarization

g_1 results





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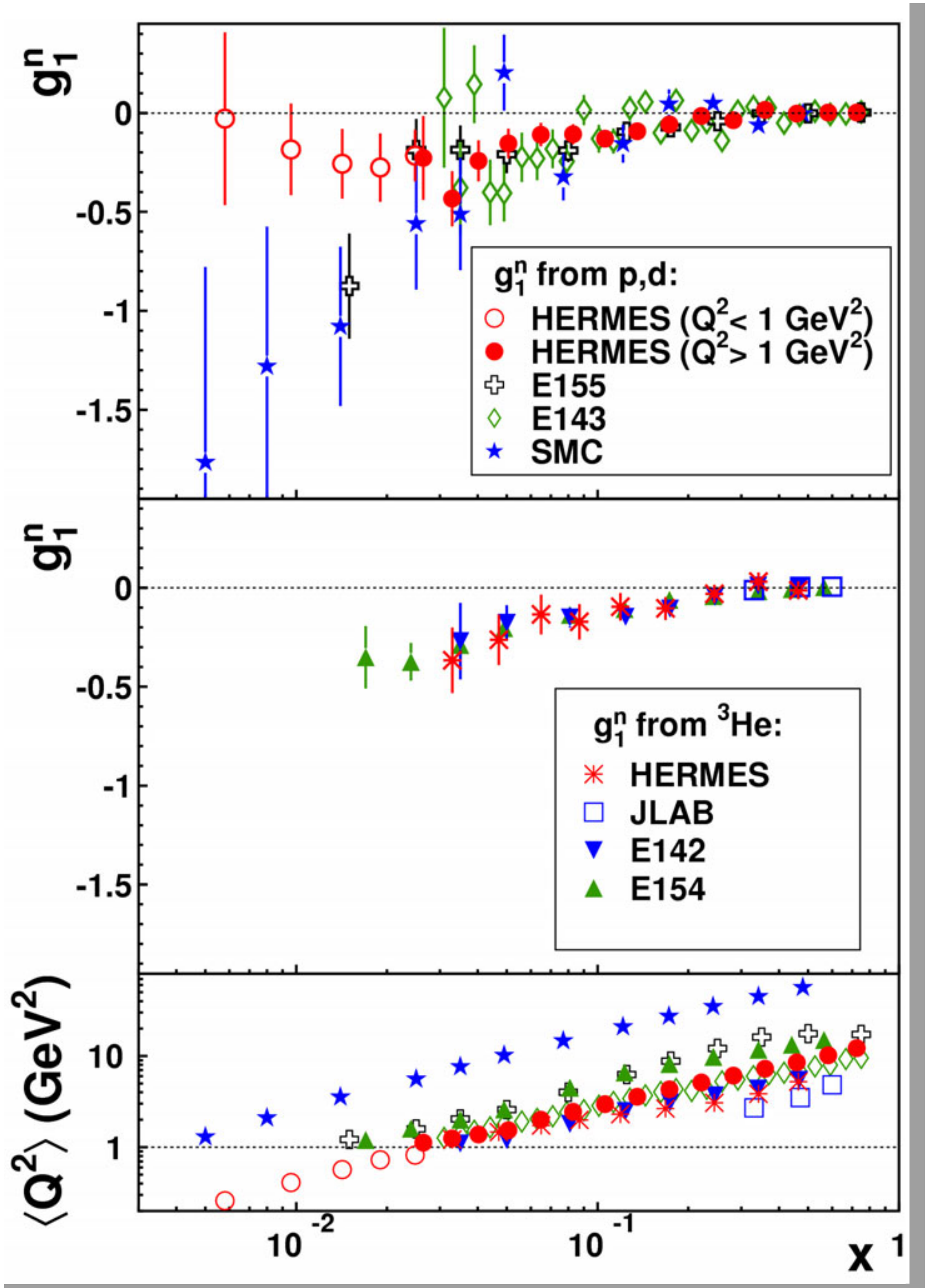
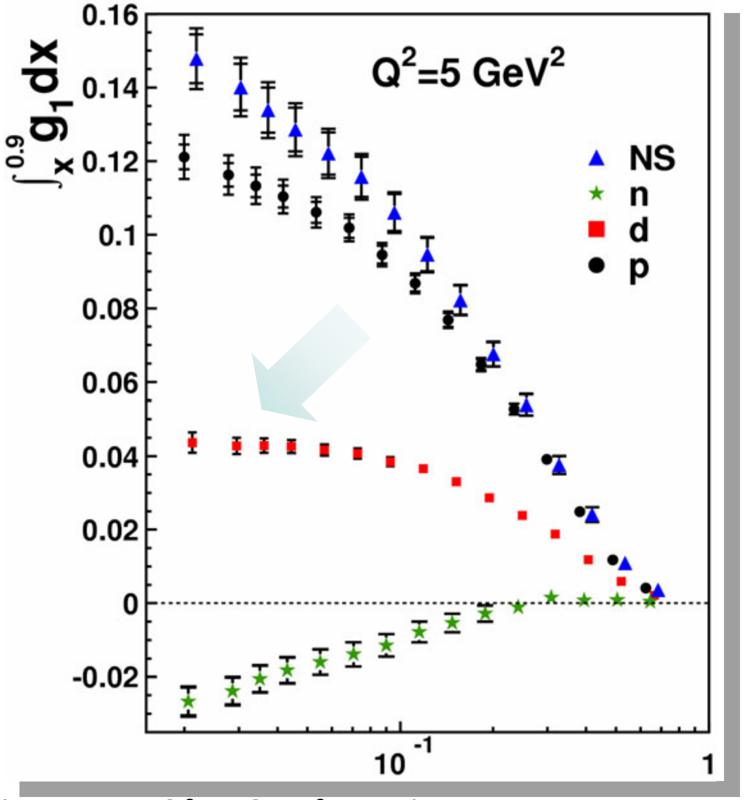


Neutron results

$$g_1^n = \frac{2}{1 - \frac{3}{2}\omega_D} \cdot g_1^d - g_1^p$$

- g_1^n **negative everywhere except at very high-*x***
- **Low-Q^2 data tends to zero at low-*x***
  - **Does not support earlier conjecture of strong decrease for** $x \to 0$

Integrals



(use only Q^2>1GeV^2 data)

Saturation in the deuteron integral is assumed

➡ *Use only deuteron data!*

from hyperon beta decay (a_8=0.586±0.031)

$$a_0 = \frac{1}{\boxed{\Delta C_S}} \left[\frac{9\Gamma_1^d}{\left(1 - \frac{3}{2}\boxed{\omega_D}\right)} - \frac{1}{4}\boxed{a_8}\,\boxed{\Delta C_{NS}} \right]$$

theory *theory*

ω_D=0.05±0.05

$$\Delta u + \Delta\bar{u} = \frac{1}{6}\left[2a_0 + a_8 + 3a_3\right]$$

$$\Delta d + \Delta\bar{d} = \frac{1}{6}\left[2a_0 + a_8 - 3a_3\right]$$

$$\Delta s + \Delta\bar{s} = \frac{1}{3}\left[a_0 - a_8\right]$$

from neutron beta decay
a_3=1.269±0.003

	central value	uncertainties		
		theor.	exp.	evol.
a_0	0.330	0.011	0.025	0.028
$\Delta u + \Delta\bar{u}$	0.842	0.004	0.008	0.009
$\Delta d + \Delta\bar{d}$	-0.427	0.004	0.008	0.009
$\Delta s + \Delta\bar{s}$	-0.085	0.013	0.008	0.009

Q^2=5 GeV^2, NNLO in $\overline{\text{MS}}$ scheme

Comparisons

Exp.	Q_0^2 (GeV^2)	x range	type	Integral value	stat.	syst.	param.	evol.
E143	5	0.03 - 0.8	p	0.117	0.003	0.007		-
HERMES				0.115	0.002	0.006	0.003	0.004
SMC (*)	10	0.021-0.7	p	0.120	0.005	0.007		0.002
HERMES				0.119	0.003	0.007	0.003	0.005
EMC (*)	10.7	0.021-0.7	p	0.110	0.011	0.019		-
HERMES				0.119	0.003	0.007	0.003	0.005
E155 (*)	5	0.021-0.9	p	0.124	0.002	0.009		0.005
HERMES				0.121	0.002	0.007	0.003	0.005
E143	5	0.03 - 0.8	d	0.043	0.003	0.003		-
HERMES				0.042	0.001	0.002	0.001	0.002
SMC (*)	10	0.021-0.7	d	0.042	0.005	0.004		0.001
HERMES				0.043	0.001	0.002	0.001	0.002
E155 (*)	5	0.021-0.9	d	0.043	0.002	0.003		0.003
HERMES				0.044	0.001	0.002	0.001	0.003
E142	2	0.03-0.6	n (^{3}He)	-0.028	0.006	0.006		-
HERMES			n (p,d)	-0.025	0.003	0.007	0.002	0.001
E154 (*)	2	0.021-0.7	n (^{3}He)	-0.032	0.003	0.005		0.003
HERMES			n (p,d)	-0.027	0.004	0.008	0.003	0.002
HERMES	2.5	0.023-0.6	n (^{3}He)	-0.034	0.013	0.005		-
HERMES			n (p,d)	-0.027	0.003	0.007	0.003	0.001
HERMES/ SIDIS	2.5	0.023-0.6	NS	0.147	0.008	0.019		-
HERMES				0.138	0.005	0.013	0.005	0.003

(*): integrals re-calculated in a smaller x range, to match HERMES

- *Integrals provide a fair comparison of the accuracies of various experiments (all correlations taken into account)*
- *Proton data comparable with SLAC and CERN expts.*
- *Deuteron data is the most precise so far*

Conclusions

- ***HERMES has measured g_1 for proton and deuteron for $0.0041<x<0.9$ and $0.18\ \mathrm{GeV}^2 < Q^2 < 20\ \mathrm{GeV}^2$***

- ***Measured results are correlated no longer systematically but statistically***

- ***Integrals provide a fair comparison for the statistical accuracy of various experiments:***
  - ***Proton data precision is comparable with CERN and SLAC***
  - ***Deuteron data is the most precise so far***

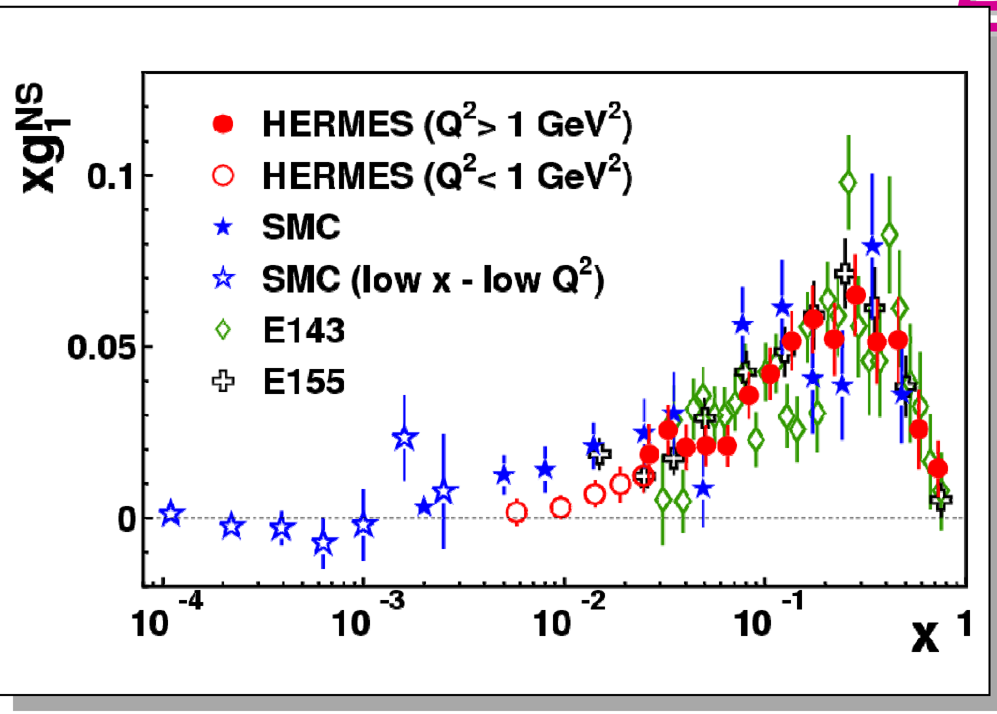
- ***The deuteron integral is observed to saturate***
  - $\boxed{a_0 = 0.330 \pm 0.011(\text{theor}) \pm 0.025\ (\text{exp}) \pm 0.028\ (\text{evol})}$ ***at 5GeV²***

agreement with COMPASS data:

$a_0(\text{COMPASS}) = 0.35 \pm 0.03(\text{stat}) \pm 0.05\ (\text{syst})$ ***at 3GeV²***

EXTRA SLIDES

Bjorken Sum Rule



$$g_1^{NS} \equiv g_1^p - g_1^n = 2\left[g_1^p - \frac{g_1^d}{1-\frac{3}{2}\omega_D}\right]$$

$$\Gamma_1^p(Q^2) - \Gamma_1^n(Q^2) = \frac{1}{6}a_3 \Delta C_{NS}(\alpha_s(Q^2))$$

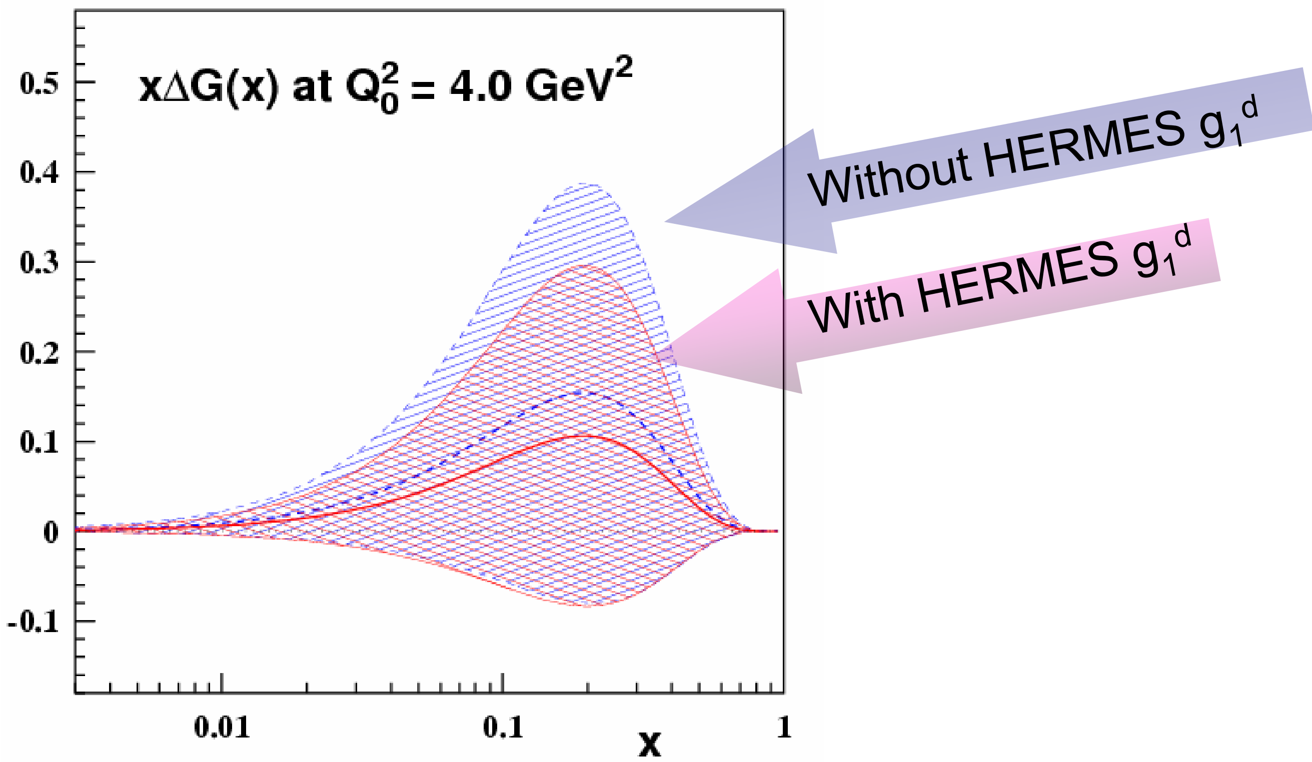
Assuming the validity of the BSR, and the saturation of the deuteron integral, we can estimate the proton integral in the unmeasured low-x region:

	BJS	Estimated $\Gamma_1^p - \Gamma_1^p(meas.)$
LO	0.2116 ± 0.0005	$0.0316 \pm 0.0008 \pm 0.0025 \pm 0.0079 \pm 0.0025$
NLO	0.1923 ± 0.0009	$0.0219 \pm 0.0008 \pm 0.0025 \pm 0.0079 \pm 0.0025$
NNLO	0.1856 ± 0.0015	$0.0186 \pm 0.0009 \pm 0.0025 \pm 0.0079 \pm 0.0025$
NNNLO	0.1821 ± 0.0019	$0.0169 \pm 0.0013 \pm 0.0025 \pm 0.0079 \pm 0.0025$

a_3, α_s, ω_D — proton integral — deuteron integral — Q^2 evolution

QCD fits to g_1 world data

(test done with BB code, Nucl.Phys.**B636**(2002)225)



- As effect of the inclusion of the HERMES data, the gluon moment goes from 0.32±0.47 to 0.22 ±0.39.
- The effect on the other parton distributions is much less visible
- $\Delta\Sigma$ =0.22 ± 0.11 ± 0.05(exp) ± 0.06(theo)

H.Boettcher, private communications

More on Integrals

Use same code as BB fit
(Blumlein&Boettcher, Nucl.Phys.B**636**(2002)225)

$$g_1(x_i, Q_i^2) = g_1(x_i, Q_0^2) + \left[g_1^{fit}(x_i, Q_i^2) - g_1^{fit}(x_i, Q_0^2) \right]$$

Evolution to a common Q^2=Q^2_0

$$\Gamma_1(Q_0^2) = \sum_i \frac{g_1(\langle x \rangle_i, Q_0^2)}{g_1^{fit}(\langle x \rangle_i, Q_0^2)} \int_{x_i}^{x_{i+1}} \mathrm{d}x \, g_1^{fit}(x, Q_0^2)$$

Integral

$$\sigma^2 = \sum_{ij} \left[\int_{x_i}^{x_{i+1}} \mathrm{d}x \, g_1^{fit}(x, Q_0^2) \right] \cdot \left[\int_{x_j}^{x_{j+1}} \mathrm{d}x \, g_1^{fit}(x, Q_0^2) \right] \cdot \frac{\mathrm{cov}\,(g_1)_{ij}}{g_1^{fit}(\langle x \rangle_i, Q_0^2)\, g_1^{fit}(\langle x \rangle_j, Q_0^2)}$$

Statistical uncertainty on the integral

The integrals at Q^2=5 GeV^2

	$\int_{0.021}^{0.9} dx g_1$	uncertainties			
		stat.	syst.	par.	evol.
		Q^2=5 GeV^2			
p	0.1211	0.0025	0.0068	0.0028	0.0050
d	0.0436	0.0012	0.0018	0.0008	0.0026
n	-0.0268	0.0035	0.0079	0.0031	0.0018
NS	0.1479	0.0055	0.0142	0.0055	0.0049