Recent results from COMPASS muon scattering measurements

Luigi Capozza

CEA Saclay - Irfu/SPhN

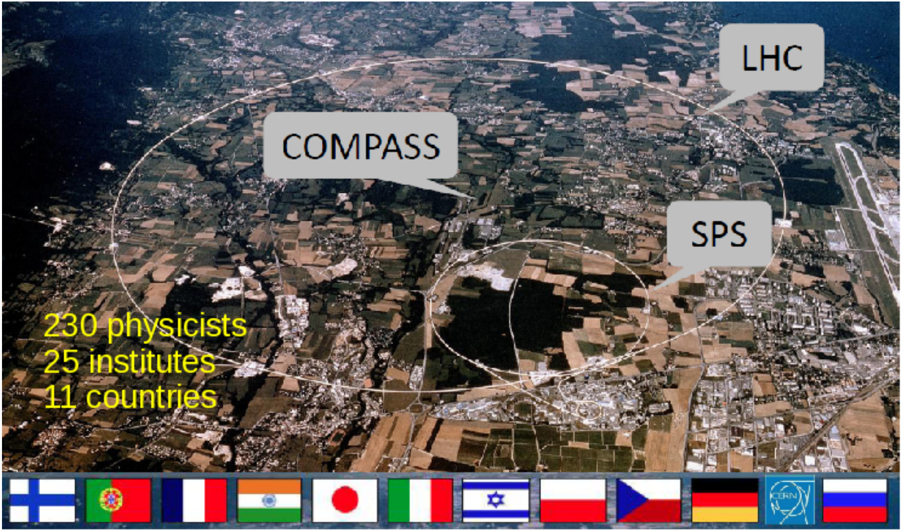
for the COMPASS Collaboration

QCD@Work 2012 – Lecce, 20 June 2011

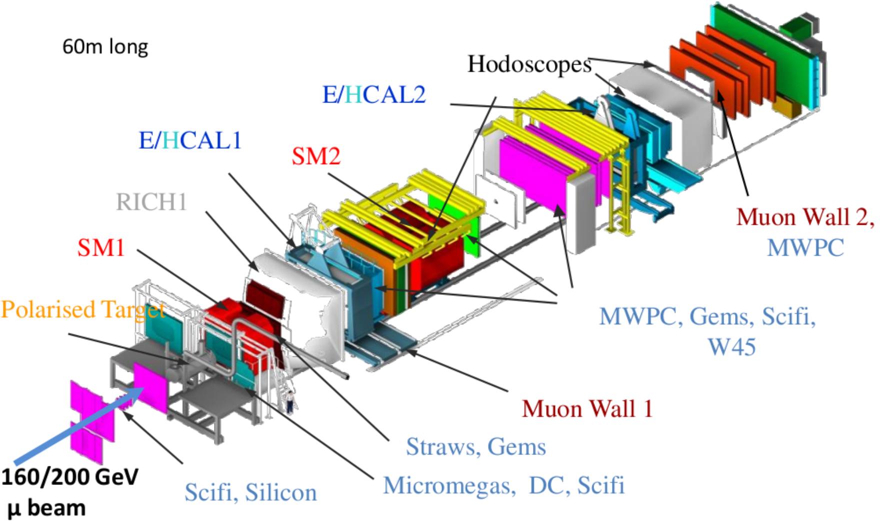
Outline

- Short overview of the COMPASS experiment
- Introduction to longitudinal spin physics
- Polarised structure functions
- Quark helicity densities
  - digression on fragmentation functions
- Gluon polarisation

The COMPASS experiment at CERN



COMPASS spectrometer



Experimental programme

Muon beam

- Deep inelastic scattering (DIS)
- Semi-inclusive DIS (SIDIS)
- Transversity
- DVCS/GPDs
- Λ polarisation

Hadron ($\pi^{\pm}$, $K^{\pm}$) beams

- Hadron spectroscopy
- Meson structure
- χPT tests
- Search for exotics
- Drell-Yan

Spin physics

- Strong interaction dynamics ⇒ spin structure of hadrons
- It is a testbed for QCD
- At high energies ⇒ pQCD + factorisation theorems
- It is a testbed for QFTs in general

In this talk: Longitudinal spin

- Mainly deep inelastic lepton scattering
- Spins (polarisations) parallel to the beam momentum
- Longitudinal polarised structure functions
- Longitudinal polarised PDFs of quarks and gluons

Longitudinal spin decomposition

- Simple decomposition of the nucleon spin ($\hbar = 1$)

$$S_N = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

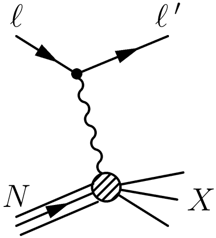
- $S_N = 1/2$: nucleon spin
- $\Delta\Sigma$: quark polarisation
- ΔG: gluon polarisation

} in this talk!

- L_z: orbital angular momentum

Polarised structure functions

$$\ell\, N \to \ell'\, (X)$$



Inclusive inelastic scattering cross section

- Structure functions:

  unpolarised: $F_1(x,Q^2)$, $F_2(x,Q^2)$
  polarised: $g_1(x,Q^2)$, $g_2(x,Q^2)$

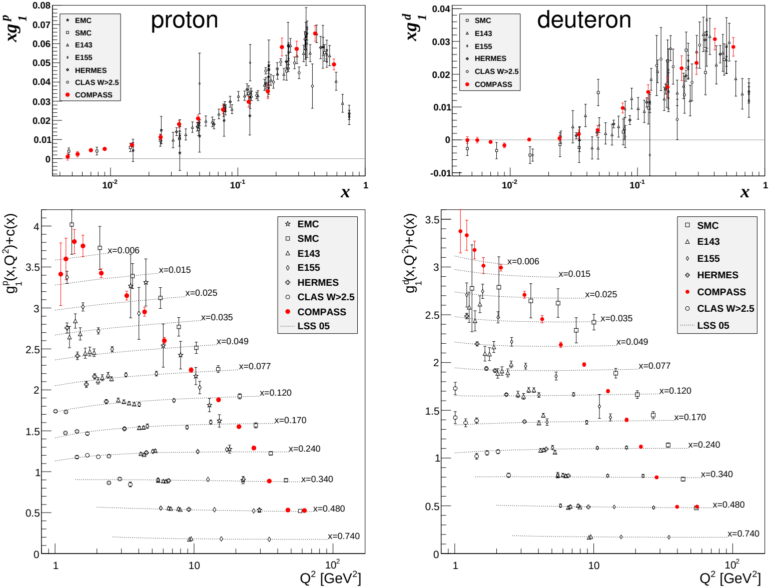
From longitudinal double-polarisation asymmetry:

$$A = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}} \Rightarrow g_1(x,Q^2)$$

At COMPASS

- polarised muon beam
- polarised proton (NH_3) and deuteron (^6LiD) targets

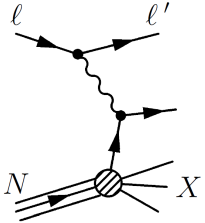
Measurements of g_1



Deep inelastic scattering (DIS)

$\boxed{\ell\, N \longrightarrow \ell'\ (X)}$ $Q^2 > 1$ GeV^2 (hard scale)

$\Rightarrow$ Scattering on quasi free partons (Factorisation + pQCD $\Rightarrow$ parton model)



unpol. σ $\Rightarrow F_1(x), F_2(x) \Rightarrow$ unpol. p.d.f. $\boxed{q(x)}$

pol. σ $\Rightarrow g_1(x), g_2(x) \Rightarrow$ pol. p.d.f. $\boxed{\Delta q(x)}$

First moment of g_1:

$$\Gamma_1 = \int_0^1 dx\, g_1(x) = \frac{1}{2} \sum_q e_q^2 \underbrace{\int_0^1 dx\ (\Delta q(x) + \Delta\bar{q}(x))}_{\equiv \Delta q}$$

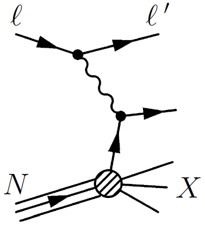
$\Rightarrow$ contributions Δq of quarks to the spin

Deep inelastic scattering (DIS)

$$\boxed{\ell\, N \to \ell'\, (X)}$$

$Q^2 > 1$ GeV^2 (hard scale)

$\Rightarrow$ Scattering on quasi free partons (Factorisation + pQCD $\Rightarrow$ parton model)



Relation with axial charges of baryons

(SU(3) flavour symmetry)

$$\Gamma_1^N \equiv \frac{1}{2}\left(\Gamma_1^p + \Gamma_1^n\right)$$
$$= \frac{1}{9} C_1^S(Q^2)\, a_0 + \frac{1}{36} C_1^{NS}(Q^2)\, a_8$$

- $C_1^{S,NS}$ calculable in pQCD
- $a_8 = 0.585 \pm 0.025$ from hyperon beta decay
- $a_0 = \Delta\Sigma$ in the $\overline{\text{MS}}$ scheme

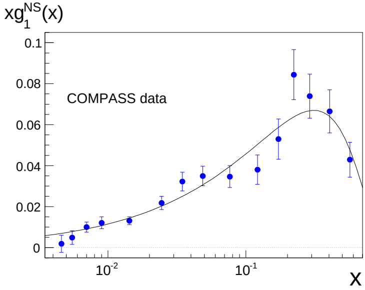
$$\Rightarrow \Delta\Sigma(Q^2 = 3(GeV/c)^2) = 0.30 \pm 0.01_{stat} \pm 0.02_{evol}$$

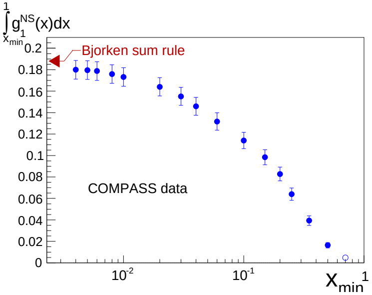
(PLB 647 (2007) 8)

Bjorken sum rule

- Validity check of this framework
- Measuring g_1^p on a proton target
- Non-singlet combination: $g_1^{NS}(x) = g_1^p(x) - g_1^n(x)$

$$\Gamma_1^{NS} = \int dx\, g_1^{NS}(x) = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C_1^{NS}(Q^2)$$





(PLB 690 (2010) 466–472)

Longitudinal spin decomposition

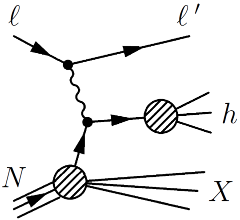
- Simple decomposition of the nucleon spin ($\hbar = 1$)

$$S_N = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

- $S_N = 1/2$: nucleon spin
- $\Delta\Sigma$: quark polarisation $\longrightarrow$ How do different flavours contribute?
- ΔG: gluon polarisation
- L_z: orbital angular momentum

Δq's from SIDIS

Semi-inclusive DIS (**SIDIS**): $\ell\, N \to \ell'\ h\ (X)$



At LO in QCD:

$$A^h(x,z) = \frac{\sigma_h^{\uparrow\uparrow} - \sigma_h^{\uparrow\downarrow}}{\sigma_h^{\uparrow\uparrow} + \sigma_h^{\uparrow\downarrow}} \qquad (z = E_h/E_\gamma)$$

$$= \frac{\sum_q e_q^2 \left(\Delta q(x) D_q^h(z) + \Delta \bar{q}(x) D_{\bar{q}}^h(z)\right)}{\sum_q e_q^2 \left(q(x) D_q^h(z) + \bar{q}(x) D_{\bar{q}}^h(z)\right)}$$

$h = \pi^+, \pi^-, K^+, K^-$...

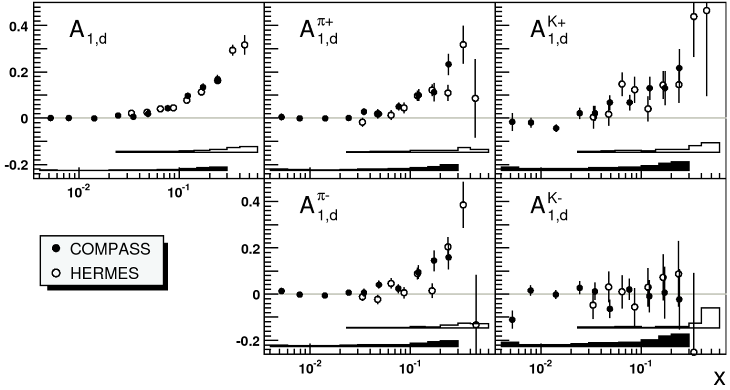
$z > 0.2$ to suppress target fragmentation

$z < 0.85$ to suppress diffractive production

- Need to identify hadrons
- RICH detector at COMPASS

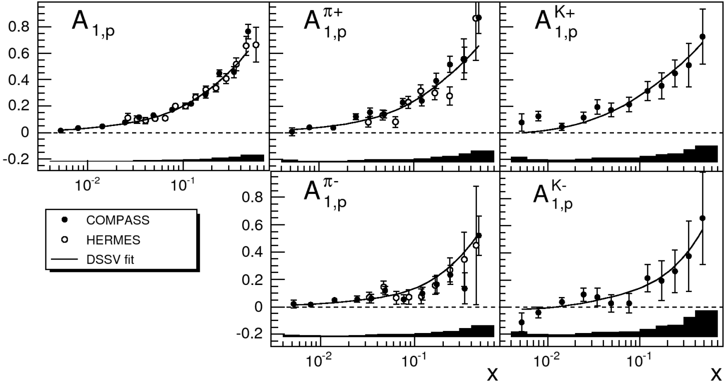
Deuteron SIDIS asymmetries

PLB 680 (2009) 217-224



Proton SIDIS asymmetries

PLB 693 (2010) 227-235



(DSSV fit: Phys.Rev.Lett. 101 (2008) 072001)

First kaon SIDIS asymmetries on a proton target

Flavour separation

$$A^h(x,z) = \frac{\sum_q e_q^2 \left(\Delta q(x) D_q^h(z) + \Delta \bar{q}(x) D_{\bar{q}}^h(z) \right)}{\sum_q e_q^2 \left(q(x) D_q^h(z) + \bar{q}(x) D_{\bar{q}}^h(z) \right)}$$

Using:

- MRST unpolarised p.d.f.
  (Phys.Lett. B636 (2006) 259)
- DSS fragmentation functions
  (Phys.Rev. D75 (2007) 114010)
- $\Delta s = \Delta \bar{s}$

For each x value:

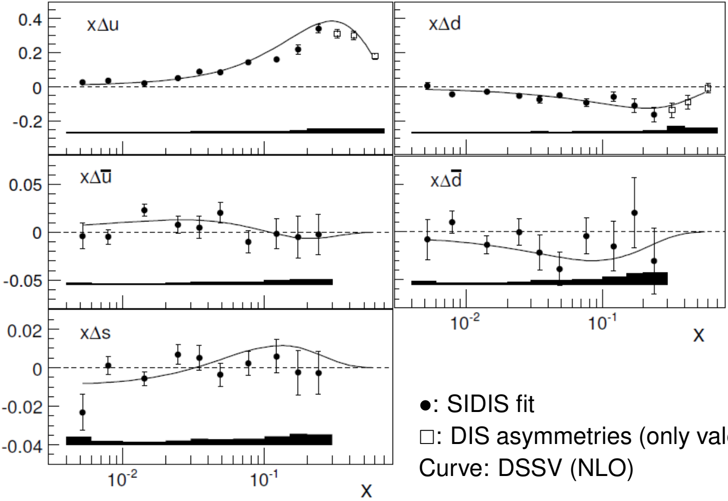
4 SIDIS measurements on d +
4 SIDIS measurements on p +
2 inclusive measurements

---

10 data points

Δu, $\Delta \bar{u}$, Δd, $\Delta \bar{d}$, Δs (=$\Delta \bar{s}$)
$\Rightarrow$ 5 unknowns

Flavour separation



●: SIDIS fit

□: DIS asymmetries (only valence)

Curve: DSSV (NLO)

The ΔS puzzle

Strangeness contribution to long. spin:

$$\Delta S = \int dx\ [\Delta s(x) + \Delta\bar{s}(x)]$$

From inclusive measurements:

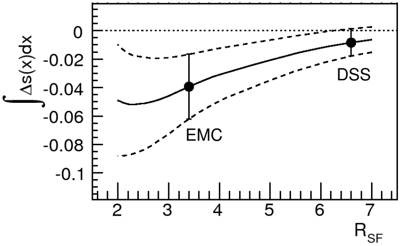
$$\Delta S = -0.08 \pm 0.01_{\text{stat.}} \pm 0.02_{\text{syst.}}$$

- $\Gamma_1 = \int g_1(x)$
- SU(3) flavour symmetry + axial charges of baryons (from β decay meas.)
- SU(3) breaking?
  (see e.g. S. D. Bass and A. W. Thomas, Phys. Lett. B684 (2010) 216)

From SIDIS:

$$\Delta S = -0.02 \pm 0.02_{\text{stat.}} \pm 0.02_{\text{syst.}}$$

- Fragmentation functions D_q^h?
- Strong dependence on the ratio: $R_{SF} = D_{\bar{s}}^{K^+} / D_u^{K^+}$



Fragmentation functions (FFs)

- $D^h_{q,g}$: mean number of h's emitted in the hadronisation of a parton
- Universal quantities describing hadronisation
- Enter every process with hadrons detected in the final state
- Mostly measured at e^+e^- colliders
  - At the Z^0 mass scale $\Rightarrow$ far from fixed target SIDIS scales
  - Mostly sensitive to singlet combinations
    $(D_\Sigma = D_u + D_{\bar{u}} + D_d + D_{\bar{d}} + D_s + D_{\bar{s}} + \ldots)$
- Can be extracted from lepton SIDIS data
  - Measuring the hadron production yield in DIS events
  - Relevant observables: "hadron multiplicities"

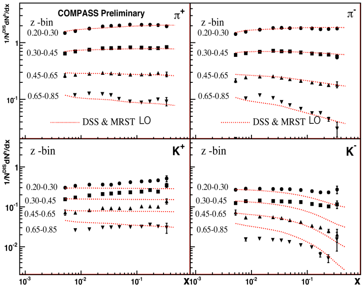
$$M^h(x, Q^2, z) \equiv \frac{d\sigma^h_{\mathrm{DIS}}/dz}{\sigma_{\mathrm{DIS}}}$$

Measurement of FFs

- Simple formula at LO:

$$M^h(x,Q^2,z) = \frac{\sum_q e_q^2\left(q(x,Q^2)D_q^h(z,Q^2) + \bar{q}(x,Q^2)D_{\bar{q}}^h(z,Q^2)\right)}{\sum_q e_q^2\left(q(x,Q^2) + \bar{q}(x,Q^2)\right)}$$

- Preliminary COMPASS results:



Comparison with the DSS parametrisation:

- For π: fair agreement
- For K: disagreement!
- To be confirmed: analysis ongoing...
- Dependence on $s(x)$?

Longitudinal spin decomposition

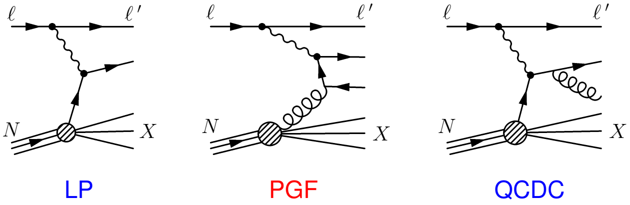
- Simple decomposition of the nucleon spin ($\hbar = 1$)

$$S_N = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

- $S_N = 1/2$: nucleon spin
- $\Delta\Sigma$: quark polarisation
- ΔG: gluon polarisation
- L_z: orbital angular momentum

Gluon polarisation

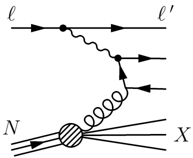
- Sensitivity to gluon PDFs needed
- Direct measurement from Photon-Gluon Fusion



- Cleanest channel: open charm ($\ell N \to \ell' D^{(*)} X$)
- High p_T hadron production
- Scaling violation of PDFs ("indirect")
- Global fits of all PDFs to different observables

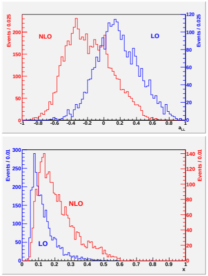
Gluon polarisation: open charm

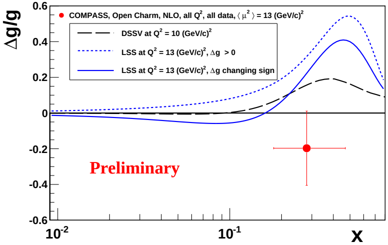
- Double-spin asymmetry in D^0/D^* production



$$\frac{\Delta g}{g} = \frac{1}{P_{\mathrm{T}}\, P_{\mathrm{B}}\, f\, a_{\mathrm{LL}}\, \frac{S}{S+B}}\, A_{\mathrm{raw}}$$

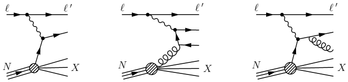
- Disadvantage: low statistics
- Preliminary NLO extraction from COMPASS data
- a_{LL} and x_g change going to NLO





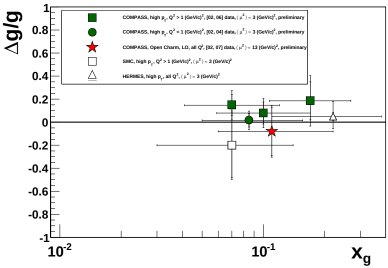
Gluon polarisation: high p_T hadrons

- All “processes” contribute



LP PGF QCDC

- At low Q^2: $> 50\%$ contribution from resolved photons
- Stronger dependence on MC
- Larger statistics than in open charm

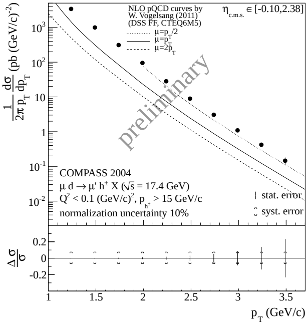


- SMC: Phys.Rev. D 70 (2004) 012002
- HERMES: JHEP 08 (2010) 130
- COMPASS: hep-ex/1202.4064 (submitted to PLB)

Gluon polarisation: global fits

- Measure Δg sensitive observables
- E.g. $A^h(p_T)$: double polarisation asymmetry of hadron production ($\gamma\,\mathrm{d} \rightarrow h\,X$)
- Fit them together with other observables within the same framework: factorisation + pQCD

- First feasibility check: measurement $d\sigma^h/dp_T$
- Fair agreement with pQCD calculations
- Improvement by resummation of NLL terms (see **D. De Florian,W. Vogelsang**, PRD 71 (2005) 114004)



Nucleon spin puzzle

$$S_N = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

- Simple expectation (constituent quark models): $\Delta\Sigma \approx 0.6$
- Direct measurements: $\Delta\Sigma \approx 0.3$
- Large ΔG could be the solution
- Direct measurements: small ΔG
- But the x_g range of measurements is limited (0.05 – 0.3)
- Maybe better go for global fits (an EIC would be important)
- Intense activity on L_z: transverse spin, GPDs...

Summary

- Review of longitudinal spin results from COMPASS
- Measurement of polarised structure functions
  - quark contribution to the nucleon spin ($\Delta\Sigma$)
  - check of Bjorken sum rule
- Flavour separation of polarised quark PDFs
- Preliminary results on fragmentation functions
- Status report on $\Delta G/G$

Backup

Asymmetry measurement

– Two types of target cells: u d
– Two field orientations: $+$ $-$

$\Rightarrow$ 4 measurements

$$N_i = \phi_i \, n_i \, a_i \, \sigma_{\text{unpol}} \, (1 + P_{\text{B}} \, P_{\text{T}} \, f \, D \, A_1)$$

- ϕ: flux
- n: no. of target nucleons
- a: acceptance
- f: dilution factor
- D: depolarisation factor (depends on kinematics and $R = \sigma_L/\sigma_T$)

$$\phi_{\text{u}} = \phi_{\text{d}}$$

$$n_+ = n_-$$

$$\left(\frac{a_{\text{u}}}{a_{\text{d}}}\right)_+ = \left(\frac{a_{\text{u}}}{a_{\text{d}}}\right)_-$$

$$\frac{N_{+\text{u}} \, N_{-\text{d}}}{N_{+\text{d}} \, N_{-\text{u}}} = \frac{(1 + P_{\text{B}} \, P_{\text{T}} \, f \, D \, A_1)^2}{(1 - P_{\text{B}} \, P_{\text{T}} \, f \, D \, A_1)^2}$$

$$\Rightarrow A_1$$

$w = f \, P_{\text{B}} \, D$ known for each event $\Rightarrow$ used for weighting

Extraction of g_1^N

- g_1^N of the nucleon:
  $g_1^N = g_1^d \,/\, (1 - 1.5\omega_D)\,, \quad \omega_D = 0.05 \pm 0.01$
- g_1^d of the deuteron:
  $g_1^d = \frac{F_2^d}{2x(1+R)} A_1^d\,, \quad R = \sigma^L/\sigma^T\,, \quad A_1^d = \frac{\sigma_0^T - \sigma_2^T}{2\sigma^T}$
- What we measure is:
  $A^d = D\,(A_1^d + \eta A_2^d)$
  A_2^d is small (measured at SLAC) $\Rightarrow A_1^d \simeq A_d/D$ (D depends on R)

From PVS: e^- and ν

Negative Δs seems favoured

S. F. Pate *et al.*,

Phys. Rev. C 78 (2008), 015207