

New Measurements of $\Delta G/G$ at COMPASS

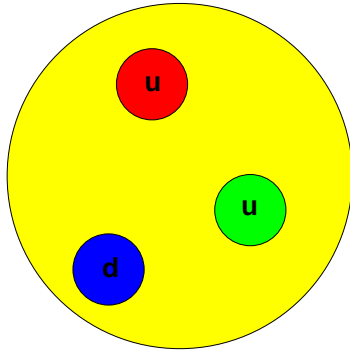
Eva-Maria Kabuß, Institut für Kernphysik, Mainz University
on behalf of the COMPASS collaboration

31. May 2006

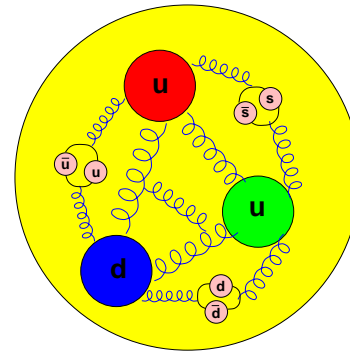
CIPANP 2006, Puerto Rico, May 30 – June 3, 2006

- Polarised DIS
- COMPASS experiment
- Longitudinal spin structure
- Gluon polarisation
- Summary and outlook

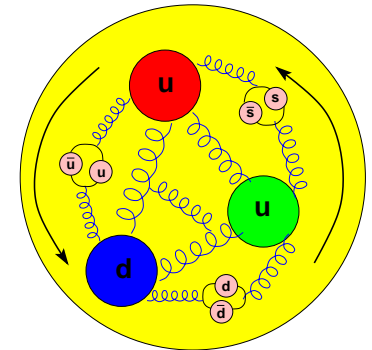
The spin of the nucleon



Naive parton model:
 $\Rightarrow \Delta\Sigma = \Delta u_v + \Delta d_v = 1$
 E155
 $\Delta\Sigma = 0.23 \pm 0.07 \pm 0.19$



gluons important in
 unpolarized case
 $\Delta G?$

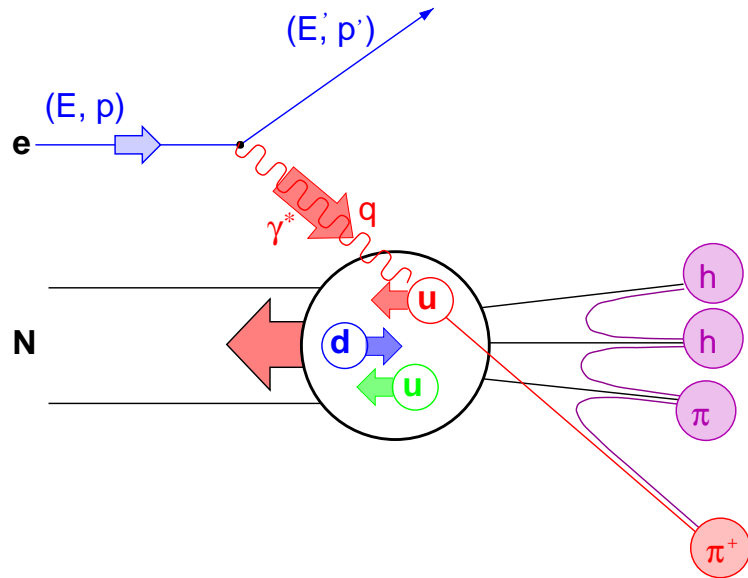


complete description:
 orbital angular momenta

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

Polarised DIS

Deep inelastic scattering



$$Q^2 = -q^2 \quad x = Q^2 / 2M\nu$$

$$\nu = E - E' \quad y = \nu / E$$

$$z = E_h / \nu$$

p_T : hadron transverse momentum

$D_q^h(x)$: fragmentation function

(from quark q into hadron h)

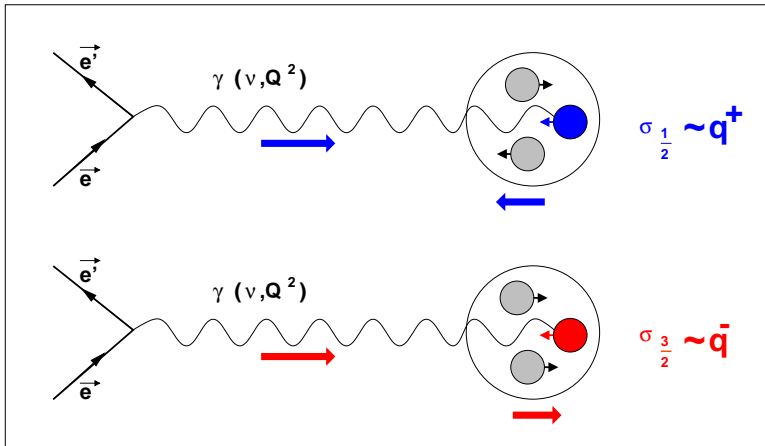
• Inclusive cross section

$$\frac{d^2\sigma}{d\Omega dE'} \sim \underbrace{c_1 F_1(x, Q^2) + c_2 F_2(x, Q^2)}_{\text{spin independent}} + \underbrace{c_3 g_1(x, Q^2) + c_4 g_2(x, Q^2)}_{\text{spin dependent}}$$

F_1, F_2, g_1, g_2 structure functions

Polarised deep inelastic scattering

- absorption of polarised photons (QPM)



$$q(x) = q(x)^+ + q(x)^-$$

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

+ quark ↑↑ nucleon
 - quark ↓↑ nucleon

- photon nucleon asymmetry

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_q e_q^2 (q(x)^+ - q(x)^-)}{\sum_q e_q^2 (q(x)^+ + q(x)^-)} = \frac{g_1(x)}{F_1(x)}$$

- spin structure function

$$g_1 = \frac{1}{2} \sum_q e_q^2 \Delta q(x) = A_1 \cdot \frac{F_2}{2x(1+R)} \approx \frac{A_{\parallel}}{D} \cdot \frac{F_2}{2x(1+R)}$$

COMPASS at CERN

Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg,
Lissabon, Mainz, Moscow, Munic, Nagoya, Prague, Protvino, Saclay, Tel Aviv,
Turino, Trieste, Warsaw
(28 institutes, 240 physicists)

CO_{MMON} MUON AND P_{ROTON} A_{PPARATUS}
FOR S_{TRUCTURE} AND S_{PECTROSCOPY}

Muon beam

Gluon polarisation
Polarised quark distributions
Polarised fragmentation functions
Transversity
Lambda polarisation
Vector meson production
DVCS

Hadron beam

Primakoff scattering
Exotic hadrons
– Glueballs
– Hybrids
– Multi-quark states
Charmed hadrons

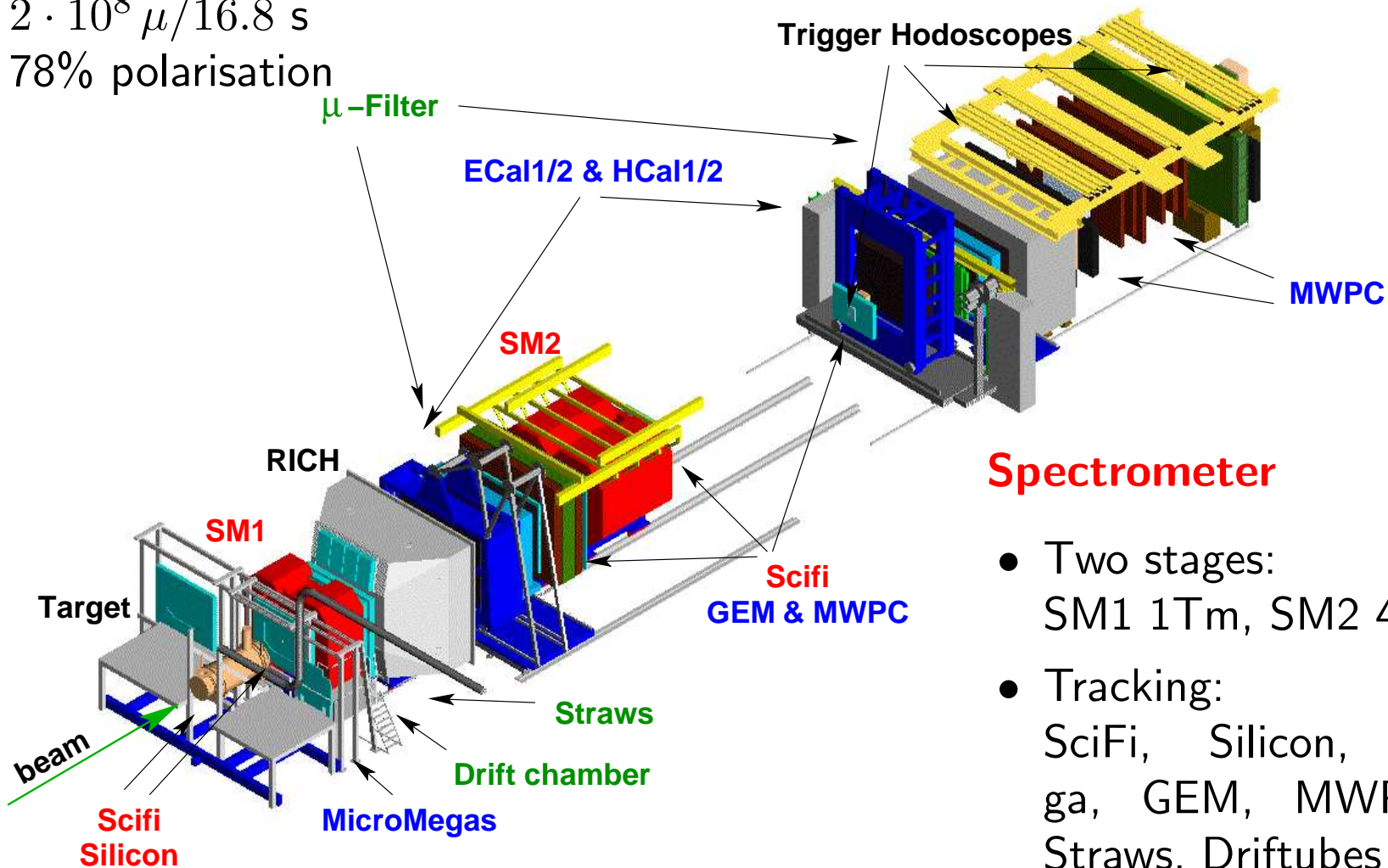
Muon beam

160 GeV/c

$2 \cdot 10^8 \mu / 16.8 \text{ s}$

78% polarisation

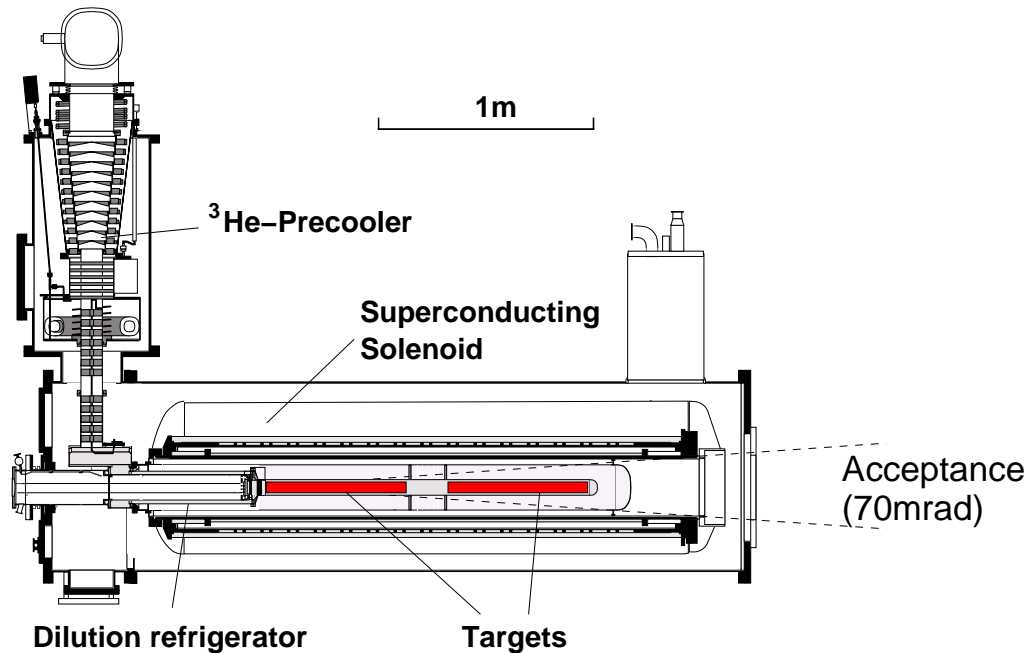
Spectrometer



Spectrometer

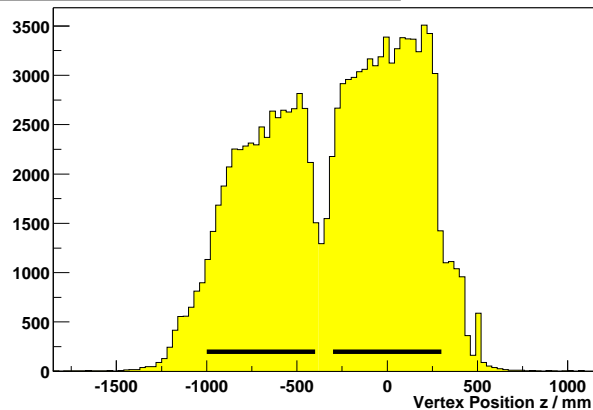
- Two stages:
SM1 1Tm, SM2 4.5Tm
- Tracking:
SciFi, Silicon, MicroMega, GEM, MWPC, Drift, Straws, Driftubes
- PID: RICH, ECAL, HCAL, muon filter

The polarised target



- Reconstructed interaction vertices

Vertex distribution along Z, $N_{\text{trk}} > 2$



- target material: ${}^6\text{LiD}$
- polarisation: $> 50\%$
- dilution factor: ~ 0.4
- Dynamic Nuclear Polarization
- solenoid field: 2.5 T
- ${}^3\text{He}/{}^4\text{He}$: $T_{\text{min}} \approx 50 \text{ mK}$
- two 60 cm long target cells with opposite polarisation
- 2006 new solenoid with 180 mrad acceptance
- regular polarisation reversal by field rotation

Method



- to be measured:

$$A_{\parallel} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}$$

- flux normalization:

$$A_{\text{exp}} = \frac{N_u - N_d}{N_u + N_d}$$

- acceptance difference:

Polarisation rotation

- take average asymmetry:

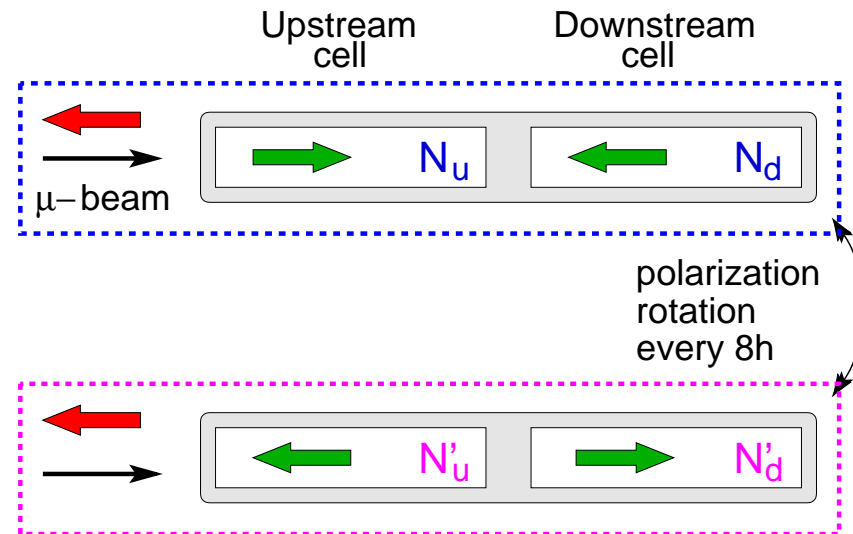
$$\Rightarrow A_{\text{exp}} = \frac{A + A'}{2} = \frac{1}{2} \left(\frac{N_u - N_d}{N_u + N_d} + \frac{N'_d - N'_u}{N'_u + N'_d} \right)$$

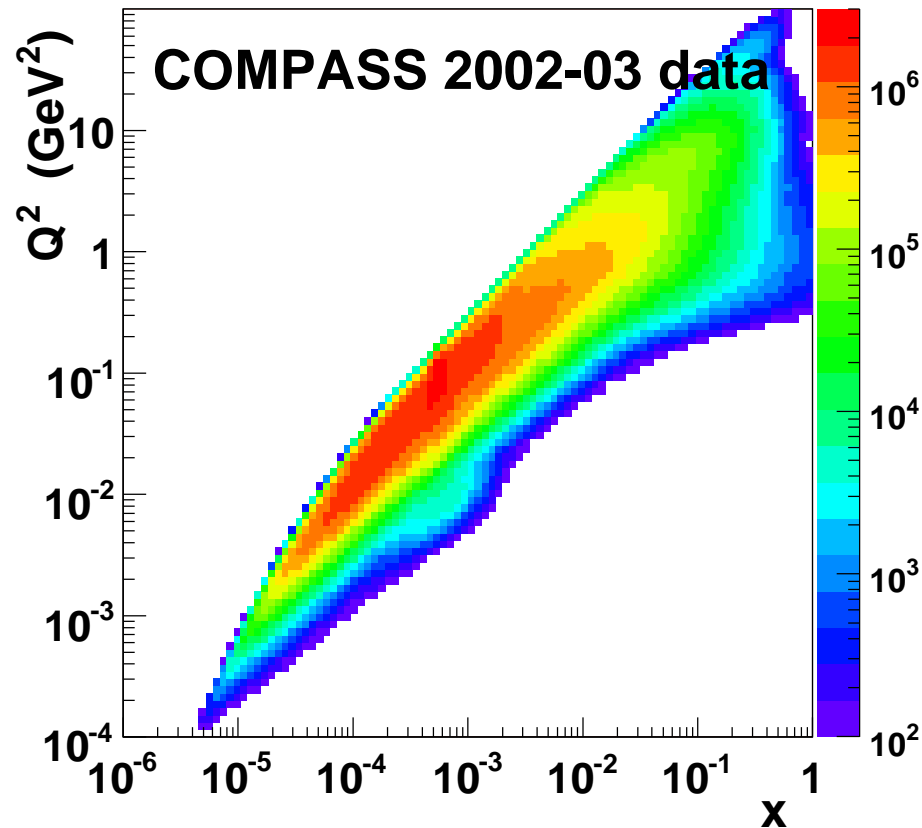
\Rightarrow minimization of bias

- experimental asymmetry

$$A_{\text{exp}} = p_{\mu} p_T f A_{\parallel}$$

p_{μ}, p_T beam and target polarisation
 f dilution factor





New results on

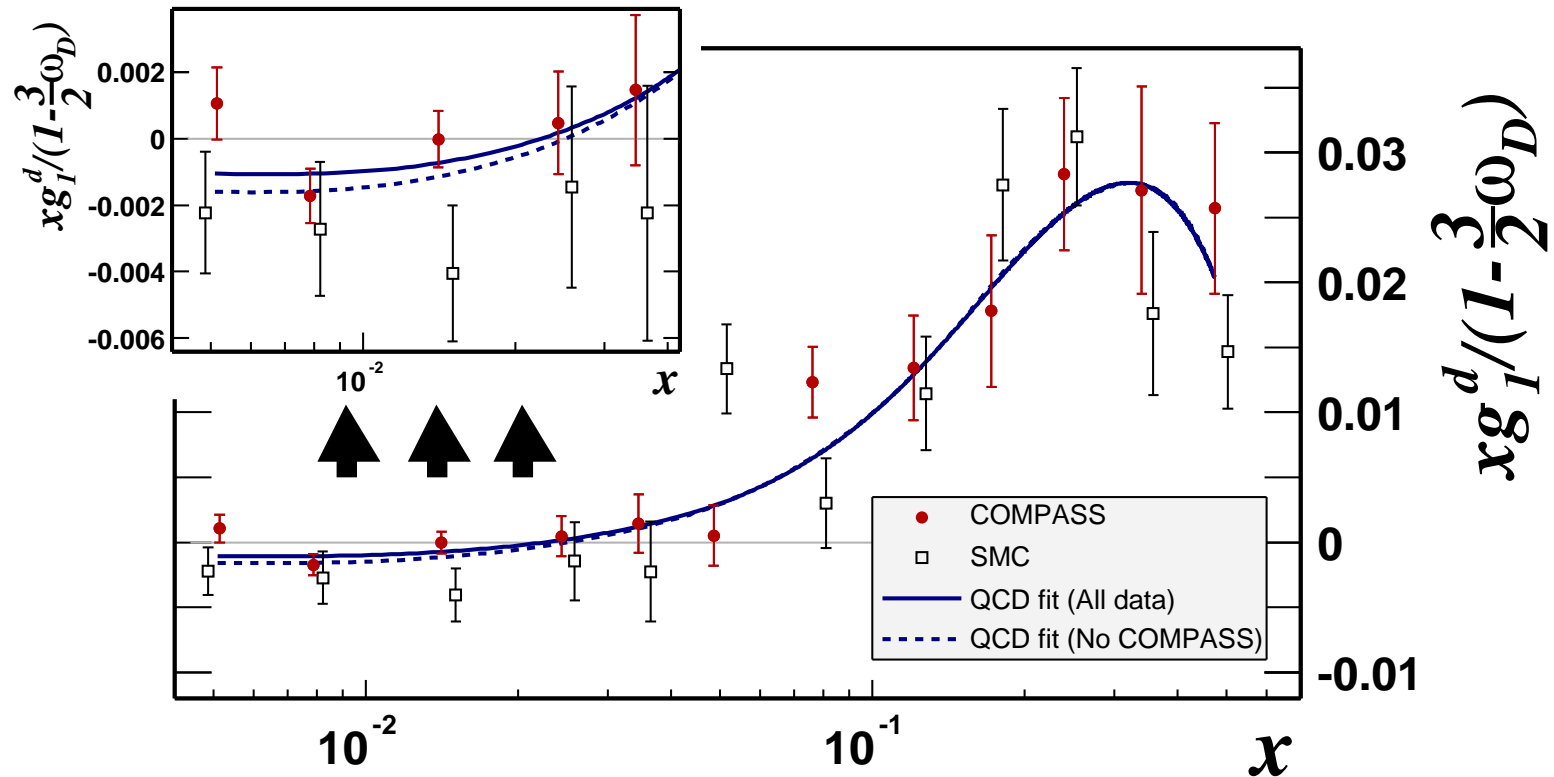
- inclusive asymmetries
- open charm production
- high p_T hadrons pairs
- Λ polarisation
- exclusive ρ production

	2002	2003	2004
Beam Time	106d	90d	110d
Preparation	30d	7d	3d
Integrated luminosity / fb^{-1} (20% for transverse target polarisation)	1	1.2	~ 2.4



Longitudinal spin structure

Inclusive asymmetries for $Q^2 > 1 \text{ GeV}^2$



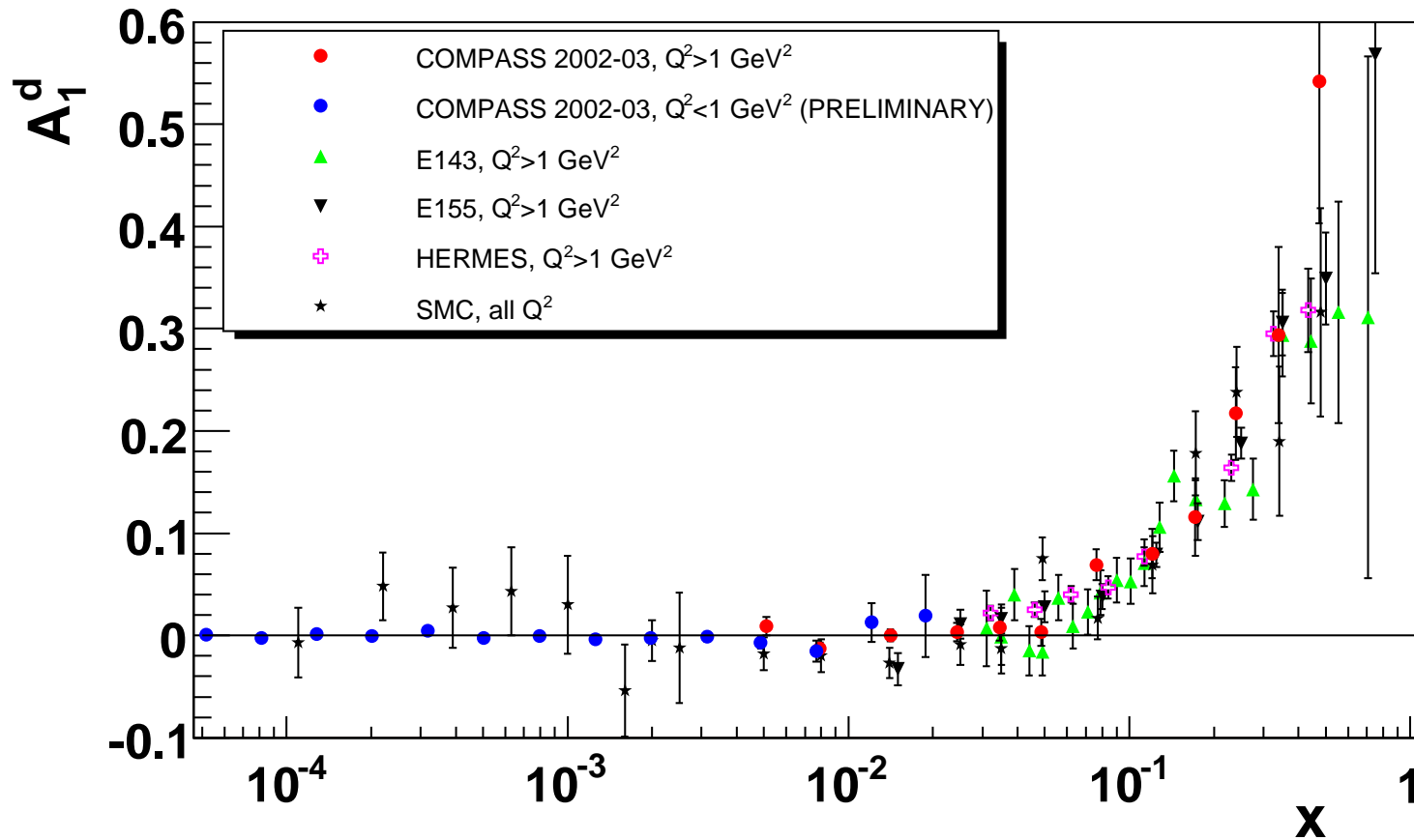
- high statistics A_1 at low x , factor 2 –3 improvement (PLB 612(2005) 154)
- xg_1 points at measured Q^2
- NLO QCD fit ($\overline{\text{MS}}$) to world data ($Q^2 = 3 \text{ GeV}^2$)

$$\Delta\Sigma = 0.25 \pm 0.02(\text{stat.}) \pm ?$$

$$\Delta G = 0.4 \pm 0.2(\text{stat.}) \pm ?$$

(error 0.03 without COMPASS data)

Inclusive asymmetries for $Q^2 < 1 \text{ GeV}^2$

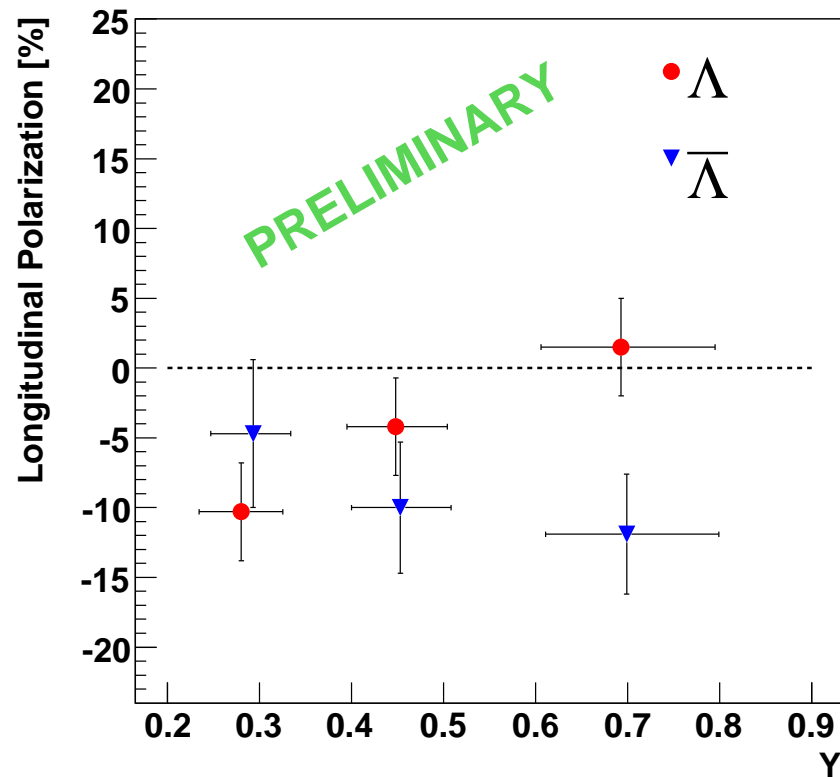


- 2002 – 2003 data, COMPASS error 10 times smaller than previous measurement
- A_1^d is compatible with 0 at small x
- more data for $Q^2 < 1 \text{ GeV}^2$ and $Q^2 > 1 \text{ GeV}^2$, semi-inclusive asymmetries

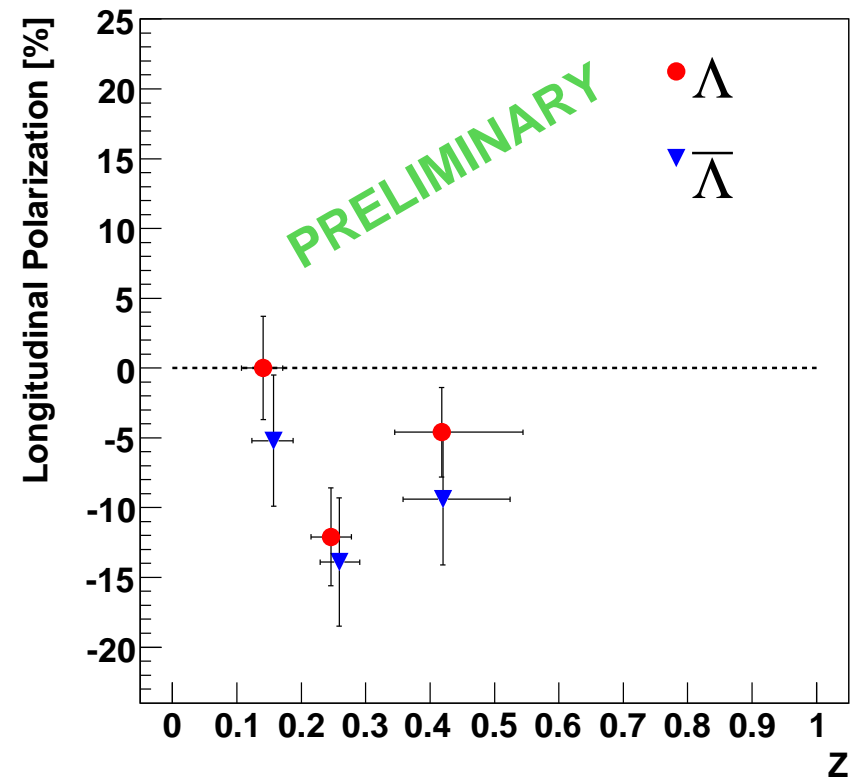
Longitudinal Λ and $\bar{\Lambda}$ polarisation



COMPASS 2003

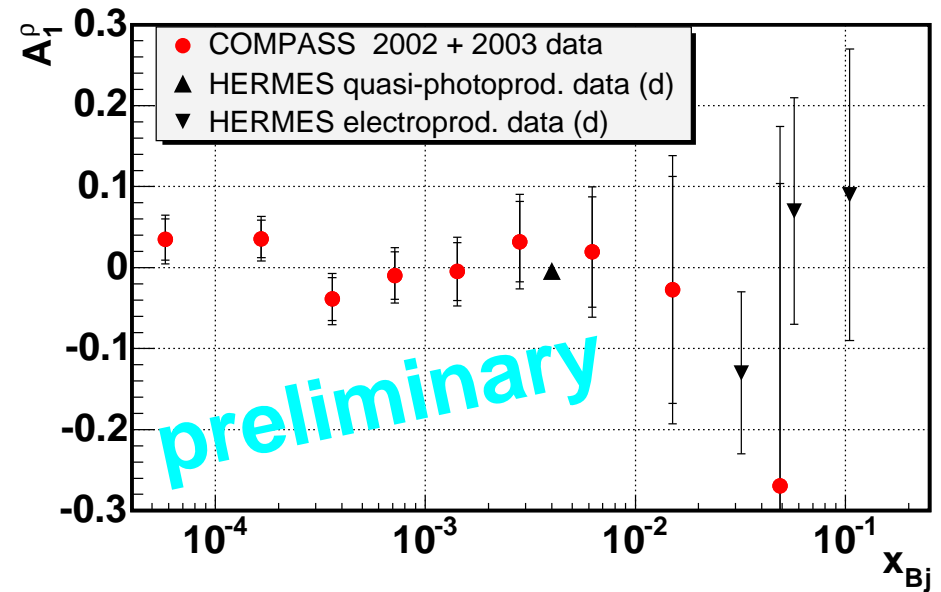
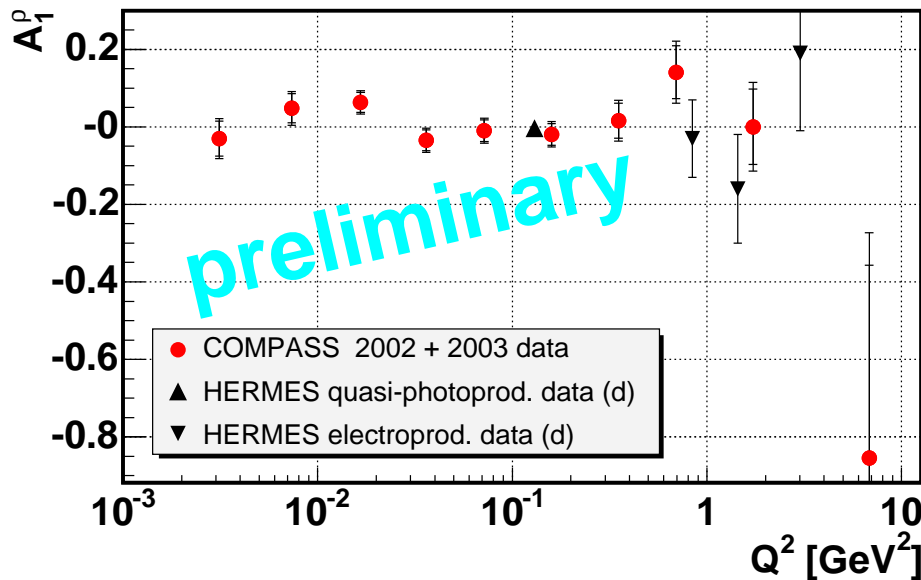


COMPASS 2003



- Λ polarisation related to spin transfer from struck quark \rightarrow sensitivity to Δ_s ?
- 2003 data: 31000 Λ , 18000 $\bar{\Lambda}$ for $Q^2 > 1 \text{ GeV}^2$
- more data from 2004

Hard exclusive ρ^0 production



- large statistics of diffractive ρ , Φ , J/Ψ
- 2.4 M events with ρ^0 from 2002 and 2003
- large range in Q^2 and x
- A_1 for ρ^0 compatible with zero, more data from 2004
- measurement of spin density matrix elements

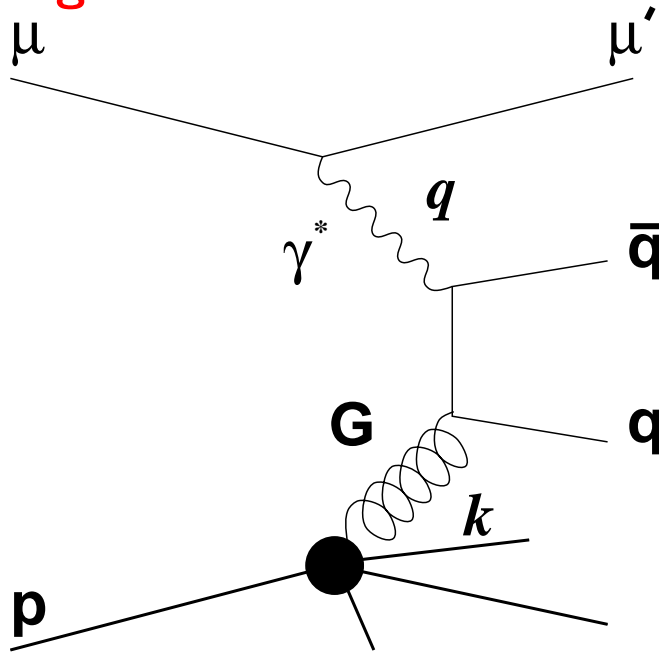


Gluon polarisation

$\Delta G/G$ measurement in DIS



- Photon gluon fusion**



$$A_{\gamma N}^{\text{PGF}} = \frac{\int d\hat{s} \Delta\sigma^{\text{PGF}} \Delta G(x_g, \hat{s})}{\int d\hat{s} \sigma^{\text{PGF}} G(x_g, \hat{s})}$$

$$\approx \langle a_{\text{LL}}^{\text{PGF}} \rangle \frac{\Delta G}{G}$$

$\langle a_{\text{LL}}^{\text{PGF}} \rangle$ analysing power

- Methods**

- **Open charm production**

$$\begin{aligned} \gamma g &\rightarrow c\bar{c} \\ &\rightarrow D^0 \rightarrow \pi K \quad \text{BR: 4\%} \end{aligned}$$

hard scale: m_c^2

clean channel,
limited statistics

- **High p_T hadron pairs**

$$\begin{aligned} \gamma g &\rightarrow q\bar{q} \\ &\rightarrow 2 \text{ jets or } H^+H^- \end{aligned}$$

hard scale: Q^2 or Σp_T^2

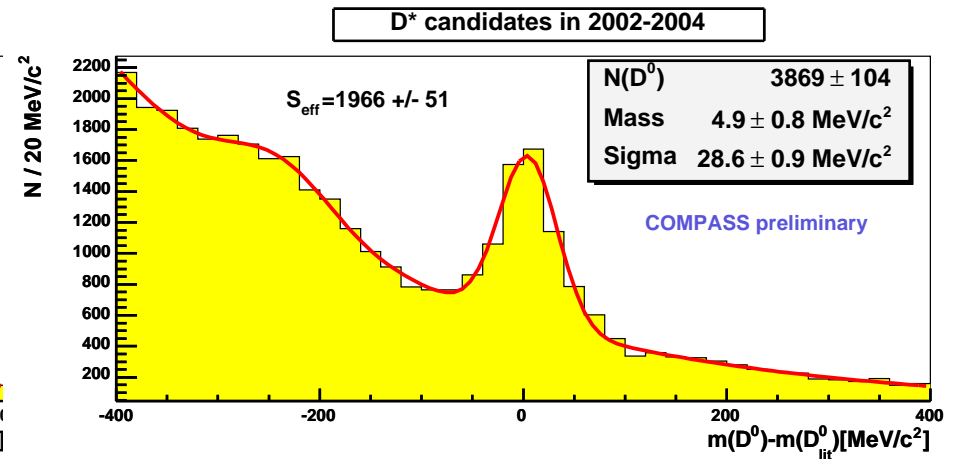
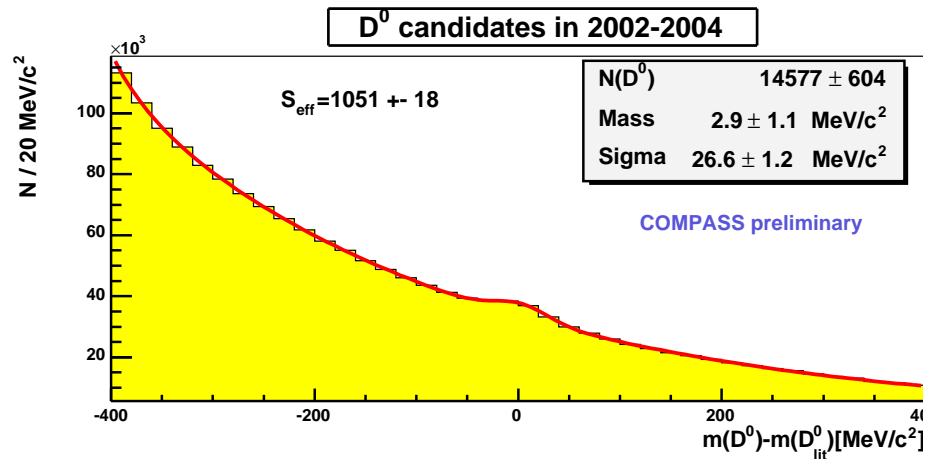
oppositely charged hadrons
pairs with large p_T und $\Delta\Phi \approx \pi$

ΔG from open charm: Mass spectra



Untagged: $D^0 \rightarrow K\pi$

Tagged: $D^* \rightarrow D^0\pi_{\text{slow}} \rightarrow (K\pi)\pi_{\text{slow}}$



- no decay vertex reconstruction
- Kaon identification by RICH essential
- cut on D^0 kinematics (z_{D^0} , $\cos(\theta)$)
- effective signal: $S_{\text{eff}} = \frac{S}{1+S/B}$
- weighting method used ($p_\mu f a_{\text{LL}} \frac{S}{S+B}$)

- cut on mass difference
 $M_{K\pi\pi} - M_{K\pi} - M_\pi$
- 3900 D^0 from D^*
- experimental asymmetry
 $A_{\text{exp}} = p_\mu p_T f a_{\text{LL}} \frac{S}{S+B} \frac{\Delta G}{G}$

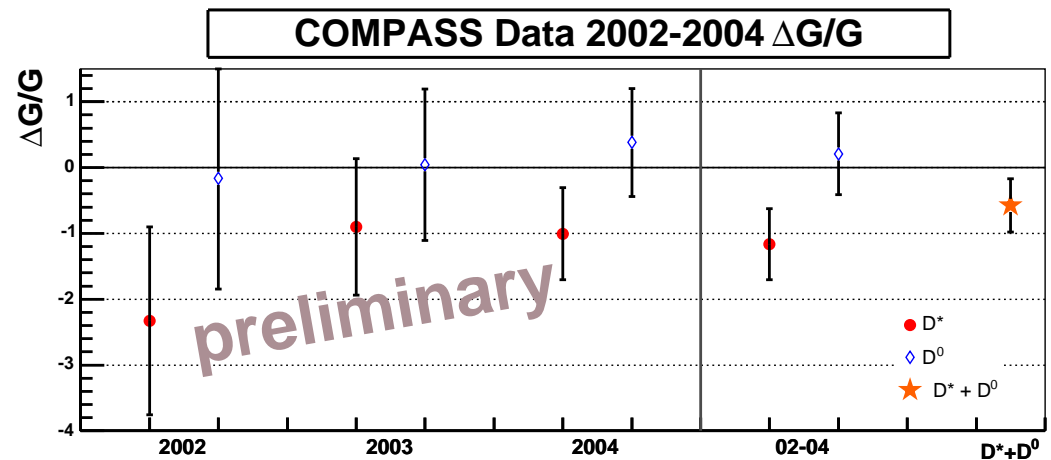
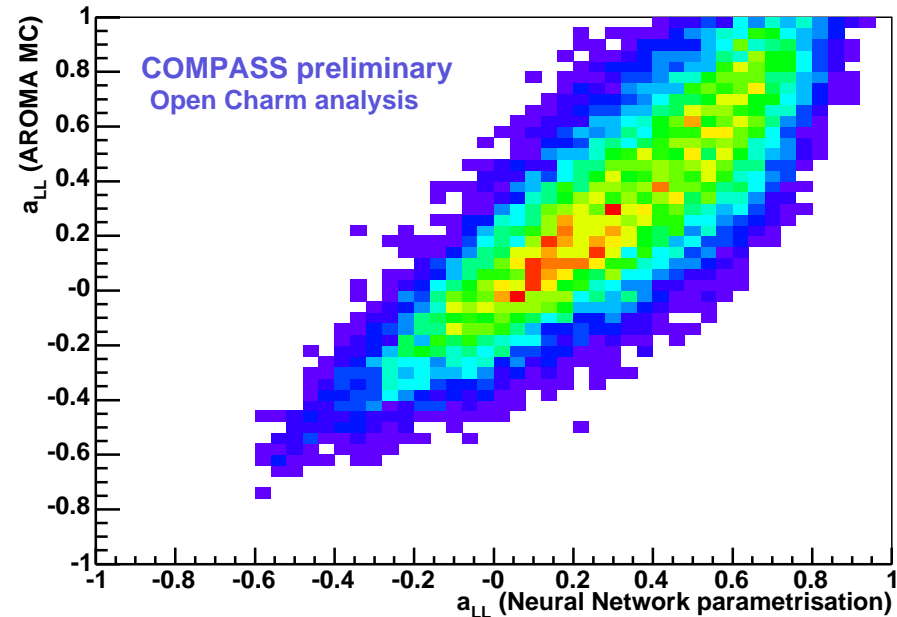
Extraction of $\Delta G/G$



- $\langle a_{LL}^{PGF} \rangle$ not exactly calculable from data
- MC with **AROMA** generator
- good description of data distributions by MC
- parametrisation determined with neural net
- **preliminary** result at $\langle x_g \rangle = 0.15$ (RMS: 0.08) from 2002–2004

$$\Delta G/G = -0.57 \pm 0.41 \text{ (stat)}$$

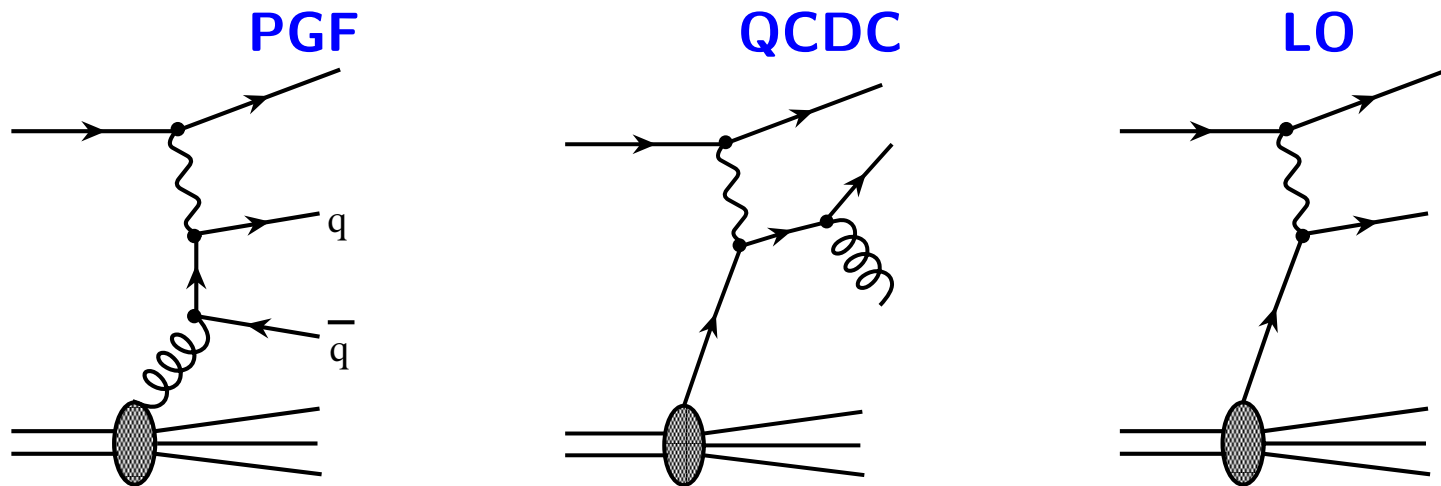
- systematic error under study e.g. false asymmetries, background asymmetries



High p_T hadron pairs ($Q^2 > 1 \text{ GeV}^2$)



- contributions to experimental asymmetry



$$\frac{A_{\parallel}}{D} = R_{\text{PGF}} \left\langle \frac{A_{LL}^{\text{PGF}}}{D} \right\rangle \frac{\Delta G}{G} + \left(R_{\text{QCDC}} \langle A_{LL}^{\text{QCDC}} \rangle + R_{\text{LO}} \langle A_{LL}^{\text{LO}} \rangle \right) A_1^d$$

- Monte Carlo for $R, \langle A_{LL} \rangle$
- data selection

Current fragmentation: $x_F > 0.1$ and $z > 0.1$

Radiative corrections/ photon polarisation: $0.1 < y < 0.9$

High p_T : $p_{T,1}, p_{T,2} > 0.7 \text{ GeV}$ and $p_{T,1}^2 + p_{T,2}^2 > 2.5 \text{ GeV}^2$

$\Delta G/G$ for $Q^2 > 1 \text{ GeV}^2$



- 2002/03 data (prelim.)

$$A_{\parallel}/D = -0.015 \pm 0.080 \text{ (stat.)} \pm 0.013 \text{ (syst.)}$$

- Monte Carlo sample generated with **LEPTO**
reasonable agreement with data
- additional x cut $\Rightarrow A_1^d$ small, LO and QCDC neglected

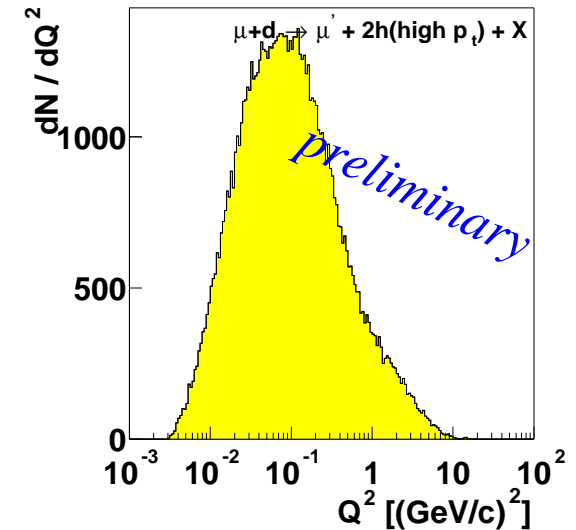
- **preliminary** result:

$$\left\langle \frac{A_{LL}^{\text{PGF}}}{D} \right\rangle = -0.75 \pm 0.05$$

$$R_{\text{PGF}} = 0.33 \pm 0.07, \langle x_g \rangle = 0.13 \text{ (RMS=0.08)}$$

$$\Delta G/G = 0.06 \pm 0.31 \text{ (stat.)} \pm 0.06 \text{ (syst.)}$$

- main contribution to systematic error: false asymmetries



- only 10% of statistics at $Q^2 > 1 \text{ GeV}^2$
- expectation 2002–2004:
 $\delta(\Delta G/G) = 0.22$
- improvement by neural net selection studied
- single hadron analysis started

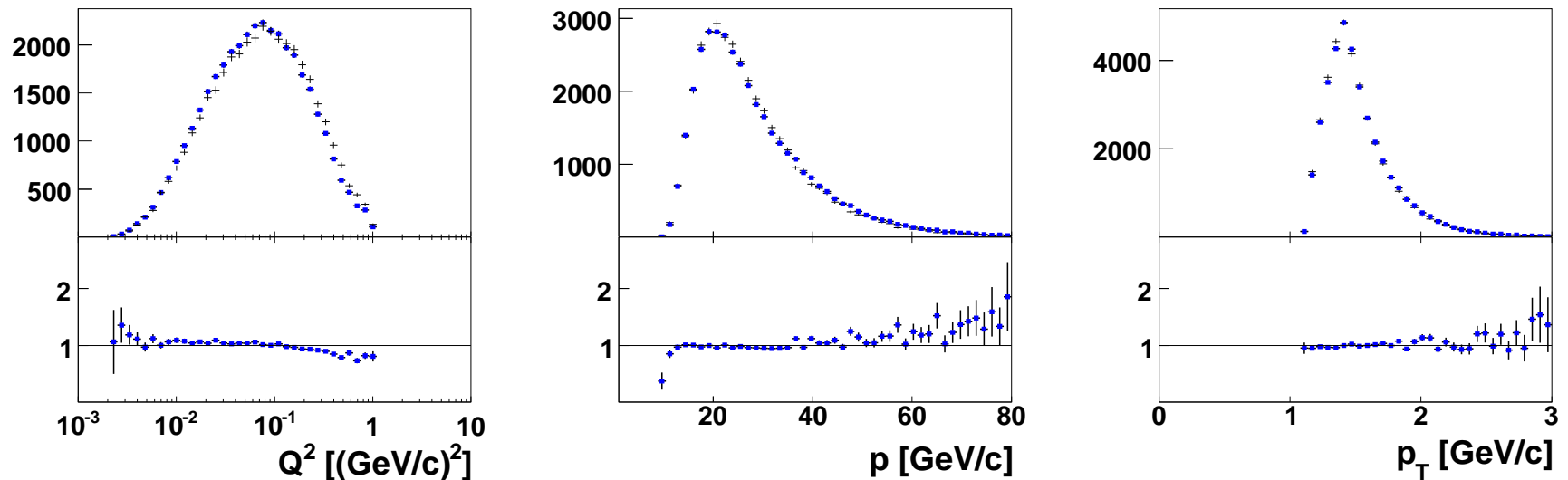
$\Delta G/G$ for $Q^2 < 1 \text{ GeV}^2$



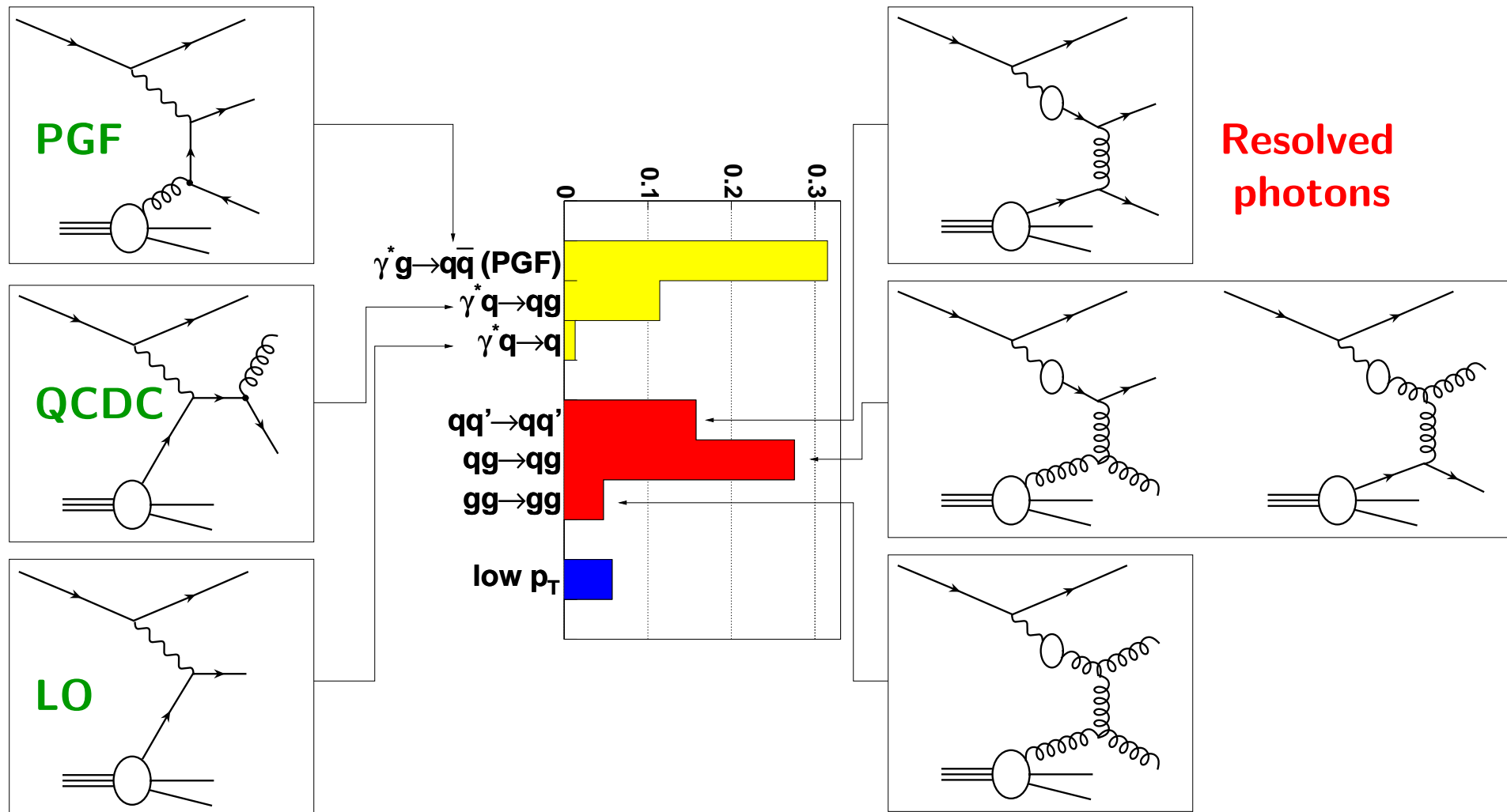
- much more statistics (500k events from 2002–2004)
but additional background from resolved photon processes
- 2002–2003 published (PLB 633 (2006) 25)
- data selection similar to large Q^2 but $0.35 < y < 0.9$
- preliminary result with $\langle D \rangle = 0.64$

$$A_{\parallel}/D = 0.004 \pm 0.013 \text{ (stat.)} \pm 0.003 \text{ (exp.syst.)}$$

- MC simulation with **PYTHIA** compared to data (blue points)



Contributions to asymmetry



- LO, low p_T neglected



Estimate of resolved photon contribution

- polarised PDFs in deuteron and photon needed
- polarised photon PDFs are sum of non perturbative and perturbative part
- estimate non perturbative contribution from unpolarised photon PDFs:

$$-q_{\text{VMD}}^{\gamma} < \Delta q_{\text{VMD}}^{\gamma} < q_{\text{VMD}}^{\gamma}$$

- use as contribution to systematic error

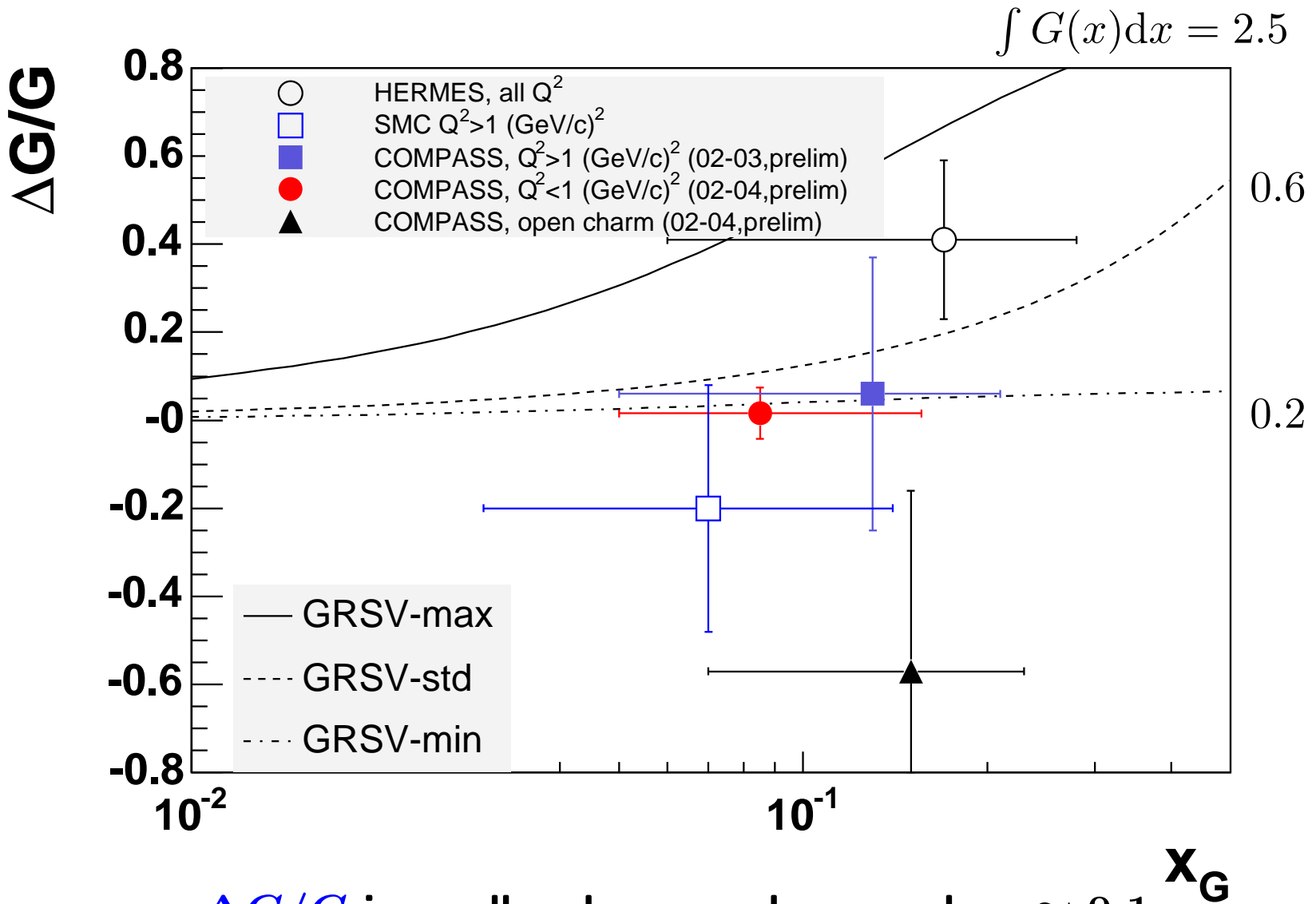
Preliminary result

- determination of R_{PGF} and a_{LL} from Monte Carlo
- most sensitive parameters in PYTHIA: k_{T}^{N} and k_{γ}^{N}

$$\Delta G/G(x_g = 0.085_{-0.035}^{+0.07}, \mu^2 = 3 \text{ GeV}^2) = 0.016 \pm 0.058(\text{stat.}) \pm 0.055(\text{syst.})$$

- systematic error includes exp. syst.(0.014) (mainly false asymmetries), MC syst.(0.052) and estimate of photon contribution (0.013)

$\Delta G/G$ measurements in DIS



$\Delta G/G$ is small or has a node around $x_g \approx 0.1$

Summary and outlook

- New results from COMPASS from 2002 – 2004 data
- Gluon polarisation measured with several methods
- New precise data for the longitudinal spin structure function at small x
- Results on ρ meson production, Λ polarisation

Plans:

- data taking continues in 2006, ^6LiD for longitudinal polarisation, NH_3 for transverse polarisation
- new target solenoid \implies larger hadron acceptance
- improvement of RICH (electronics, photon detection)
- many other detector upgrades

\implies we hope to double the statistics for most channels