New results from COMPASS

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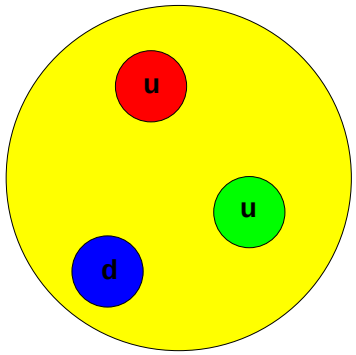
on behalf of the COMPASS collaboration

11. Juli 2005

Gordon conference on nuclear physics, Bates 2005

- COMPASS experiment
- Longitudinal spin structure
- Gluon polarisation
- Transversity
- Summary and outlook

The spin of the nucleon

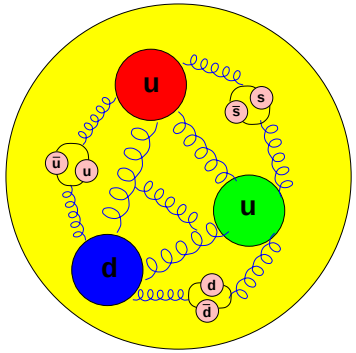


Naive parton model:

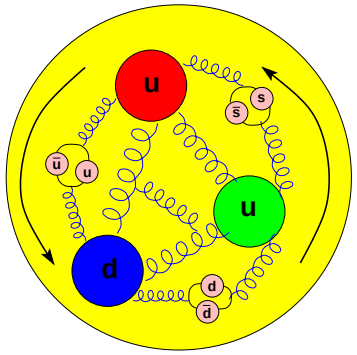
$\Rightarrow \Delta\Sigma = \Delta u_v + \Delta d_v = 1$

EMC (1988)

$\Delta\Sigma = 0.12 \pm 0.09 \pm 0.14$



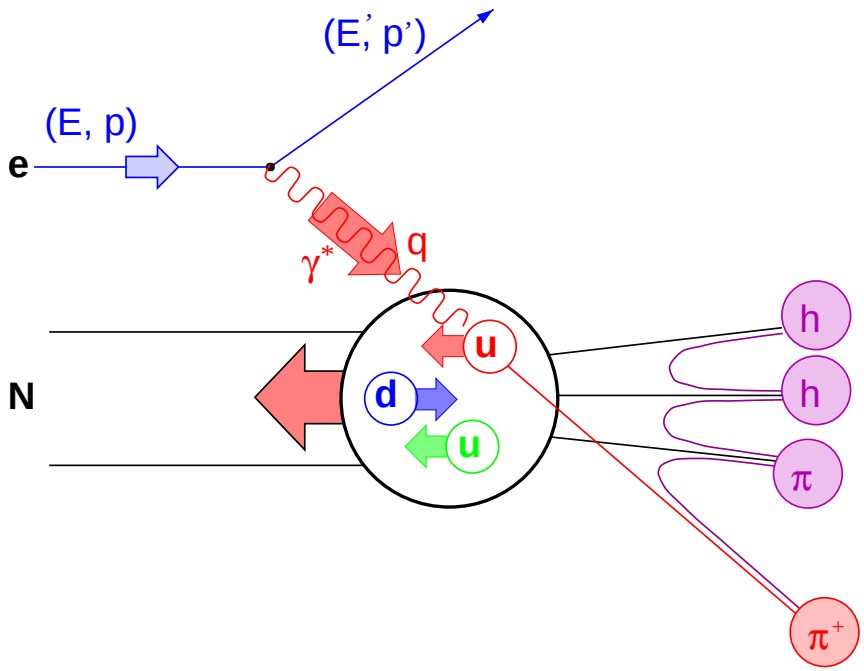
gluons important in unpolarized case



complete description: orbital angular momenta

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

Deep inelastic scattering



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

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

$$z = E_\mathrm{h}/\nu$$

p_T : hadron transverse momentum

$D_\mathrm{q}^\mathrm{h}(x)$: fragmentation function (from quark q into hadron h)

- **Inclusive cross section**

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

F_1, F_2, g_1, g_2 structure functions

COMPASS at CERN

Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg, Heidelberg, Lissabon, Mainz, Moscow, München, Nagoya, Prague, Protvino, Saclay, Tel Aviv, Turino, Trieste, Warsaw
(29 institutes, > 200 physicists)

COMMON MUON AND PROTON APPARATUS FOR STRUCTURE AND SPECTROSCOPY

Muon beam

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

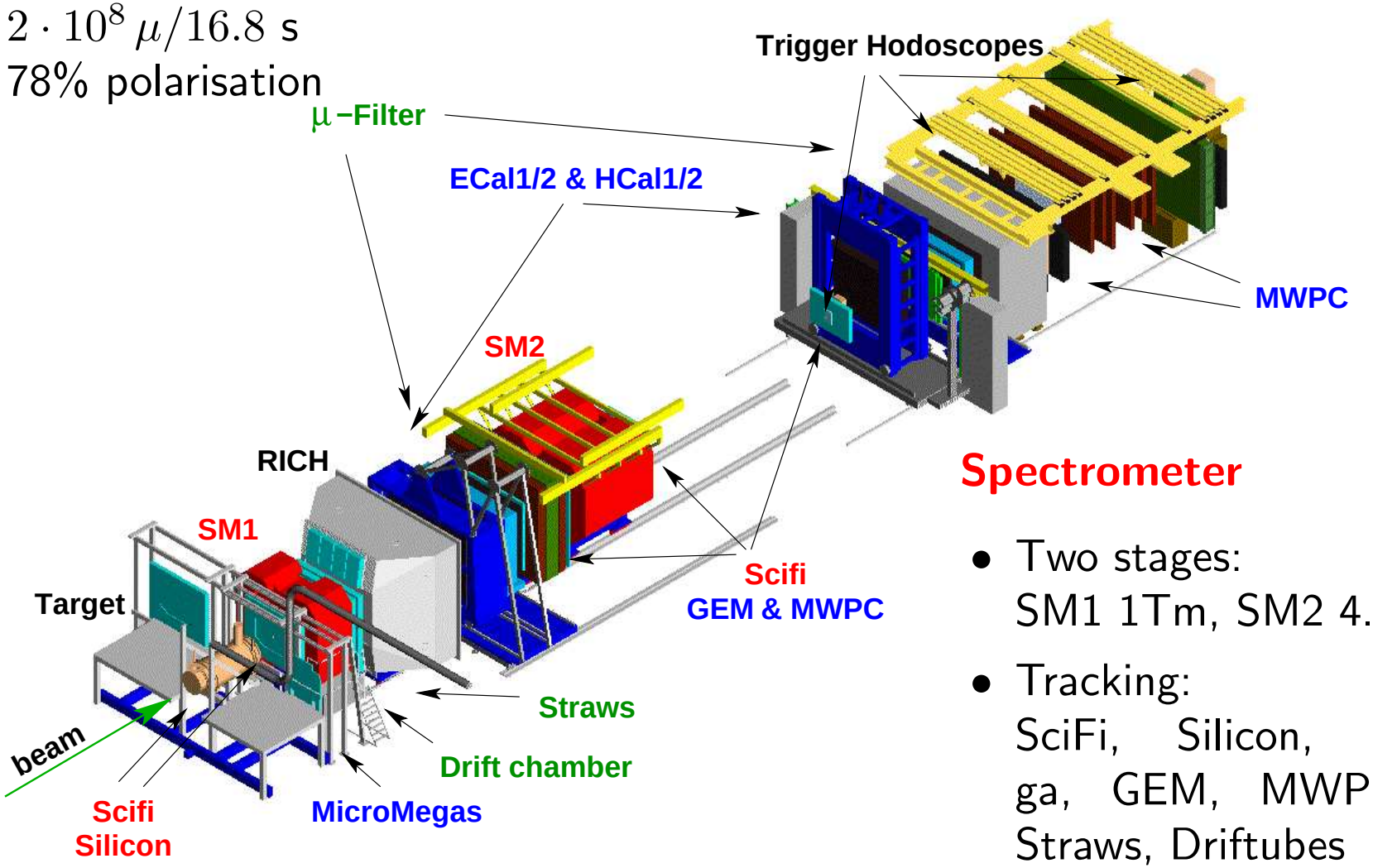
Hadron beam

Primakoff effect
Glue balls
Charmed baryons
Exotic charm states

Spectrometer

Muon beam

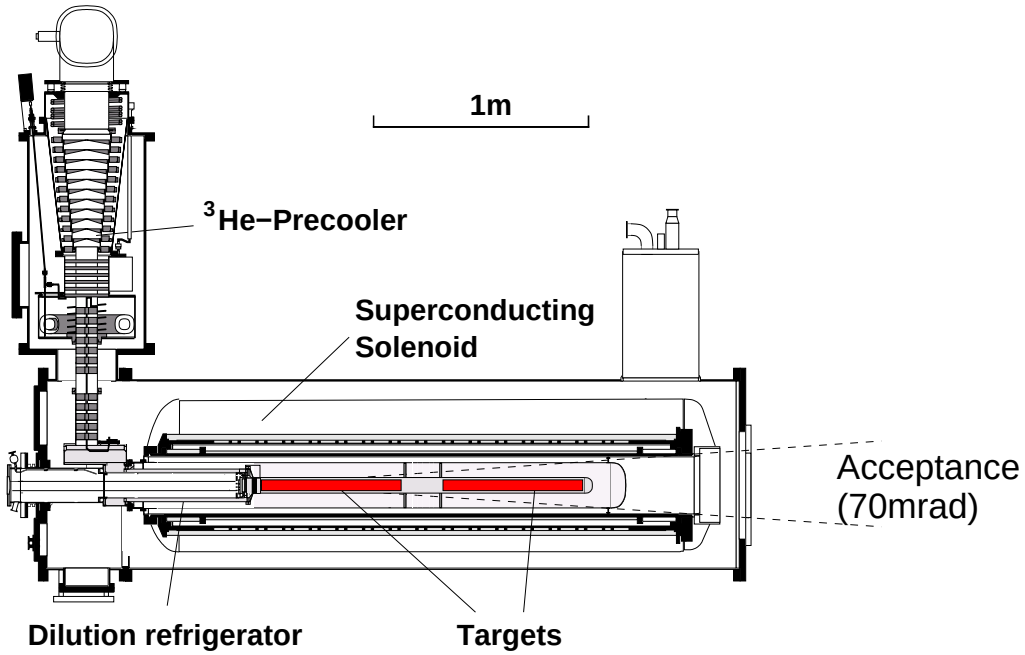
160 GeV/c
$2 \cdot 10^8\, \mu/16.8$ s
78% polarisation



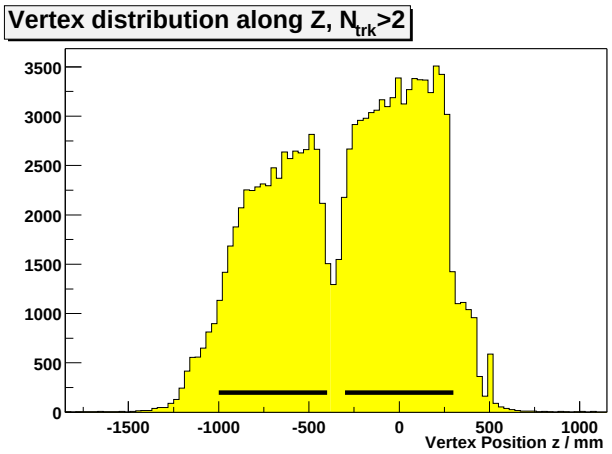
Spectrometer

- 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



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

Method

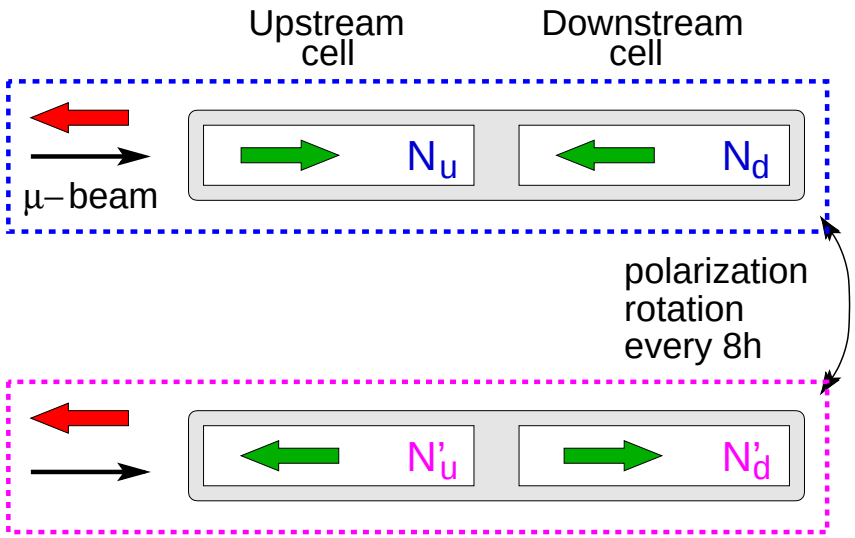
- **to be measured:**

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

- **flux normalization:**

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

- **acceptance difference:**
  Polarisation rotation



- **take average asymmetry:**

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

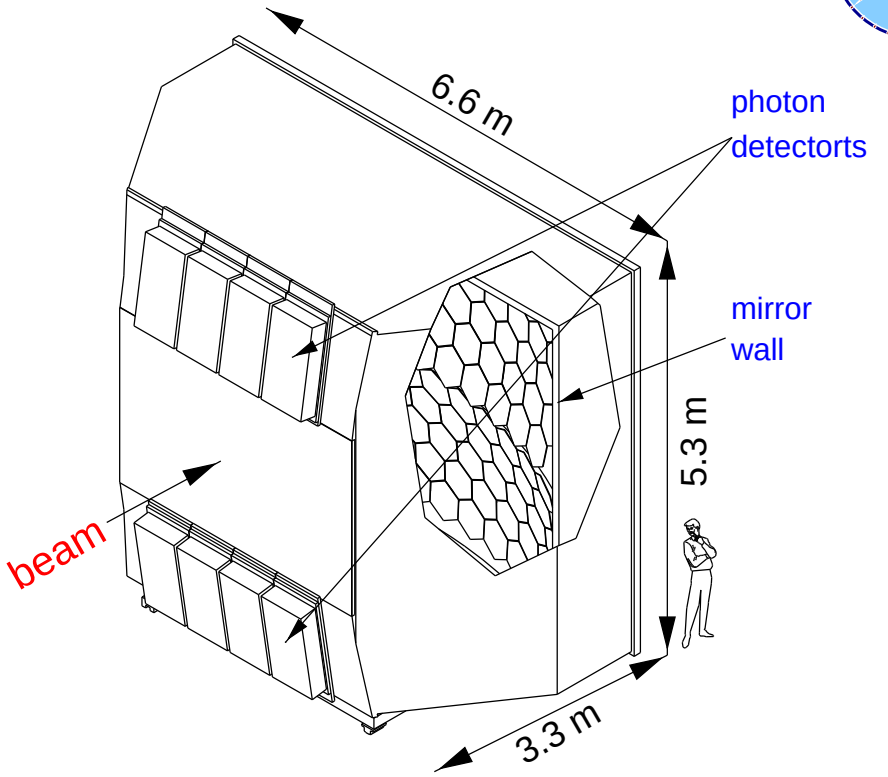
  $\Rightarrow$ minimization of bias

- **experimental asymmetry**

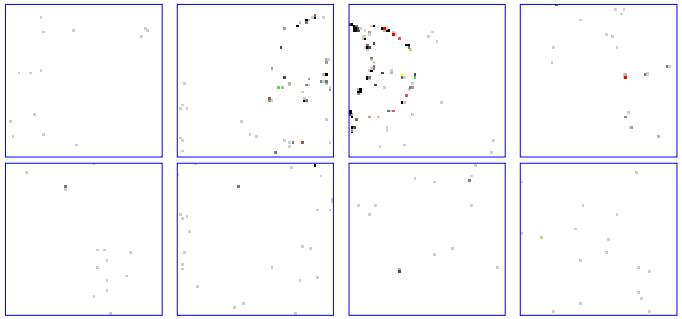
$$A_{\text{exp}} = p_\mu \; p_{\text{T}} \; f \; A_{\parallel}$$

p_μ, p_{T} beam and target polarisation
f dilution factor

πK separation with RICH



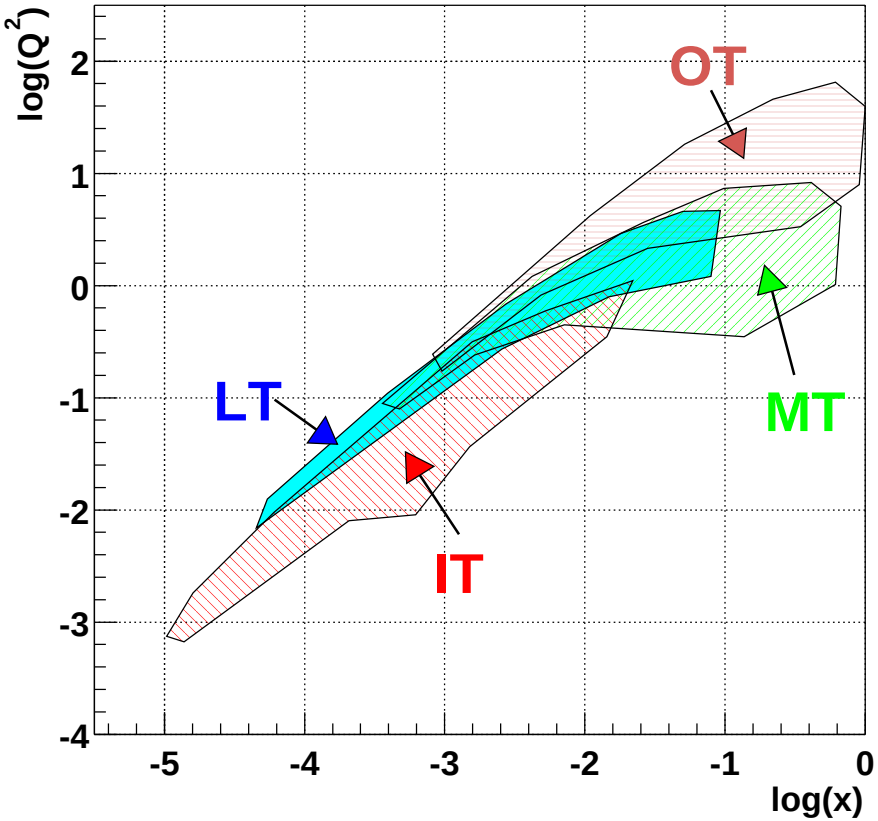
Online Event Display



- π/K separation up to 50 GeV/c
- 80 m^3 C_4F_{10}, n=1.00153
- 116 VUV spherical mirrors (21 m^3)
- MWPCs with CsI kathodes, 8×8 mm^2
- $< n >= 15$ photons

Data taking 2002 – 2004

Kinematic ranges for IT, LT, MT, OT



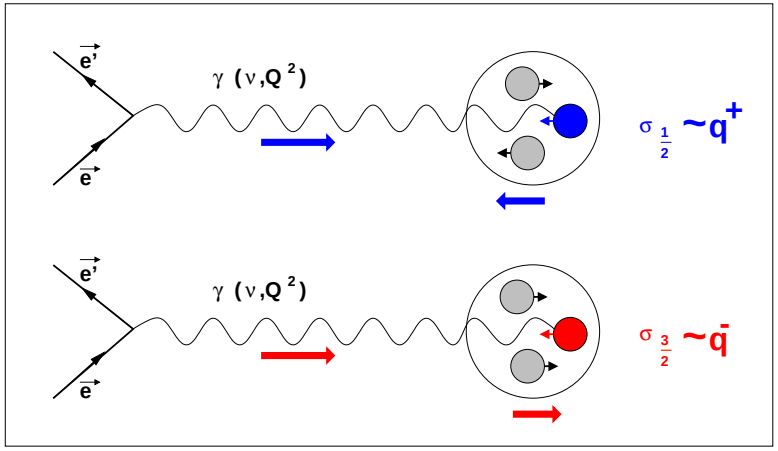
- OT, MT inclusive triggers
- IT, LT semi-inclusive triggers

	2002	2003	2004
Beam Time	106d	90d	109d
Preparation	30d	7d	3d
Integrated luminosity / fb^{-1}	1	1.2	$\sim$ 2.4

Longitudinal spin structure

Polarised deep inelastic scattering

- **absorption of polarised photons (QPM)**



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

$+$ quark $\uparrow\uparrow$ nucleon
$-$ quark $\downarrow\uparrow$ nucleon

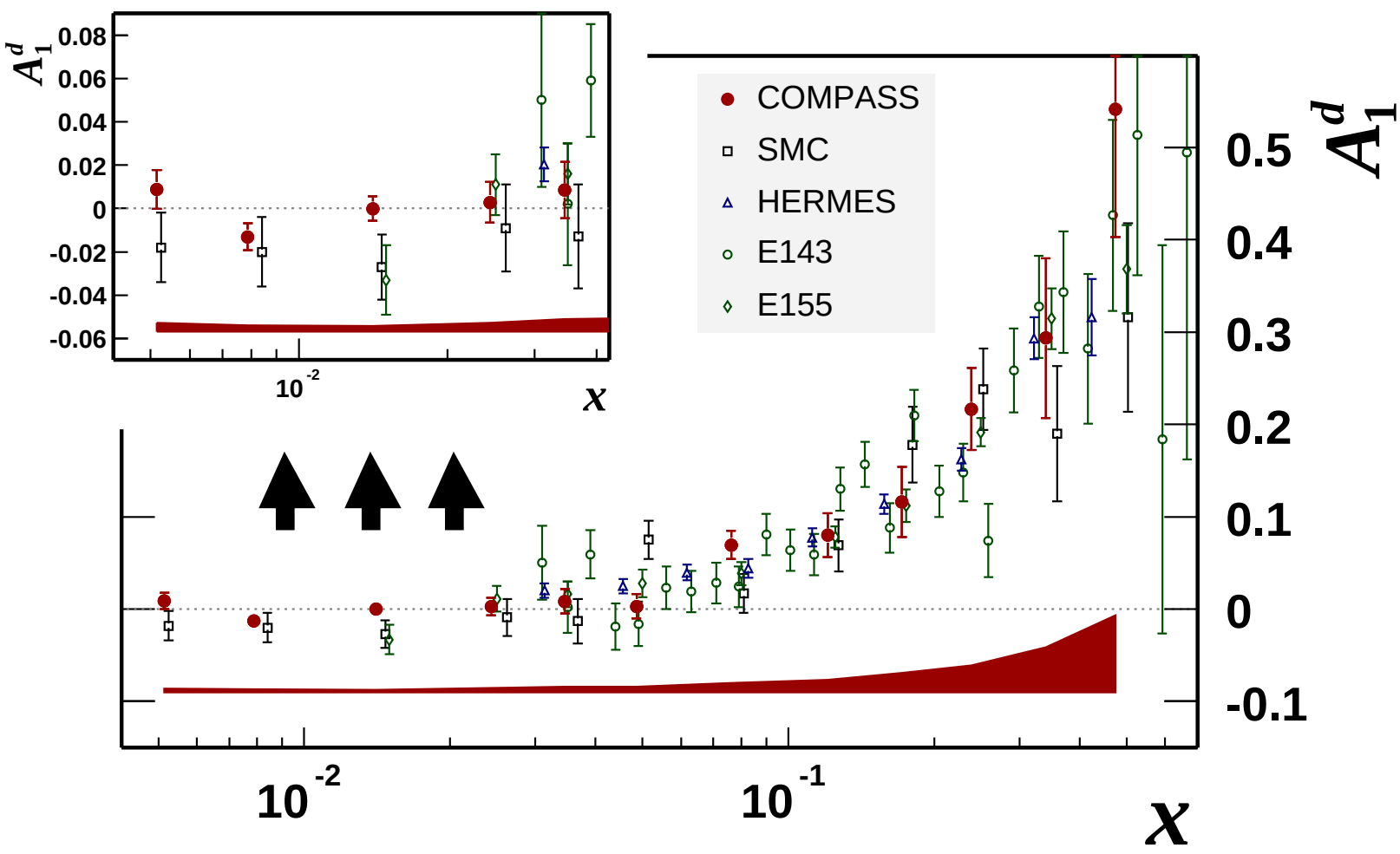
- **photon nucleon asymmetry**

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

- **spin structure function**

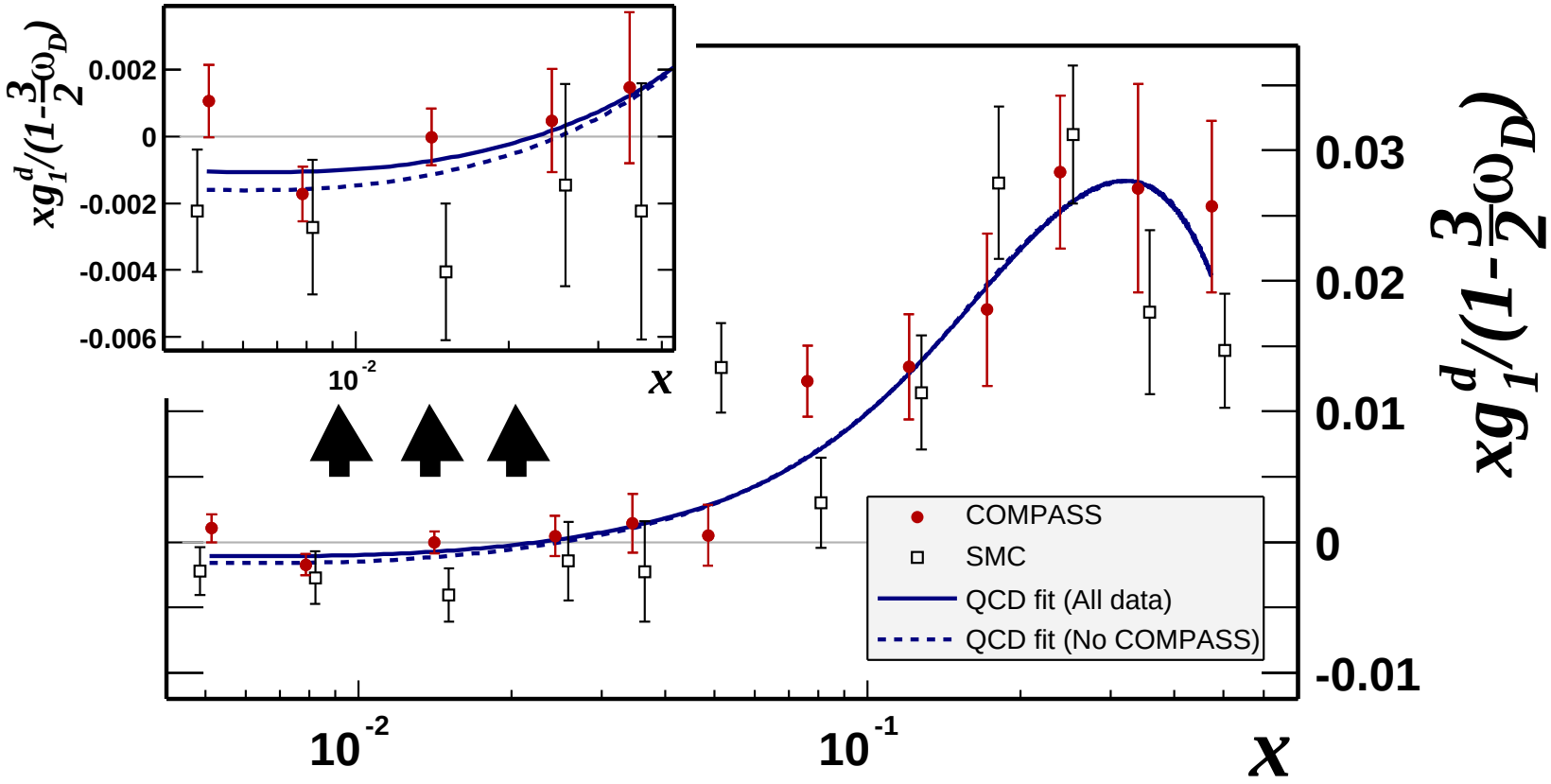
$$g_1 = \frac{1}{2}\Sigma_q\ e_q^2\ \Delta q(x) = A_1 \cdot \frac{F_2}{2x(1+R)} \approx \frac{A_\parallel}{D} \cdot \frac{F_2}{2x(1+R)}$$

Inclusive asymmetries for $Q^2 > 1$ GeV^2



- high statistics A_1 at low x, factor 2 –3 improvement
- good agreement at high x, systematically above SMC data at low x
- asymmetries for $Q^2 < 1$ GeV^2 soon

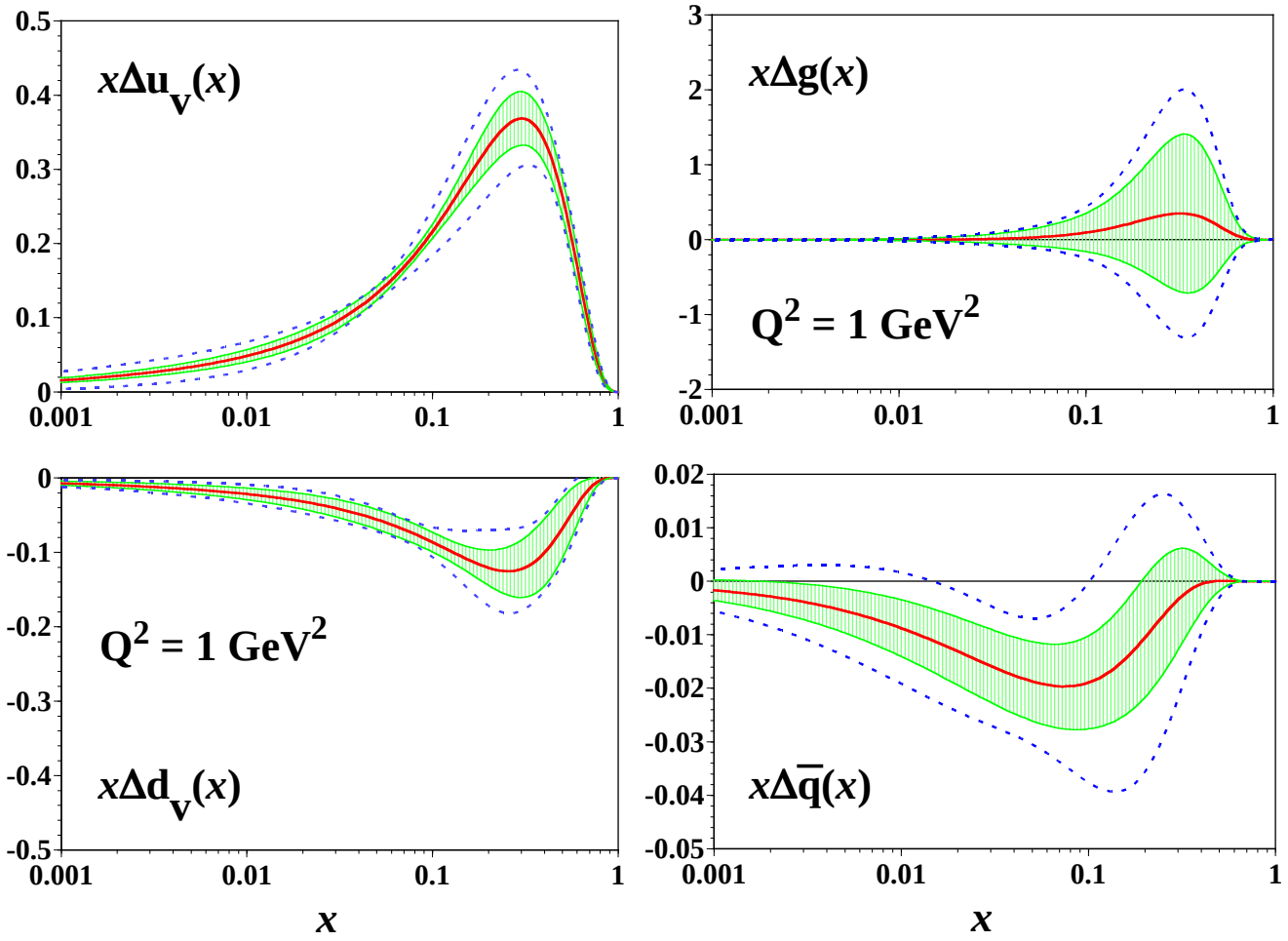
g_1 at low x



- xg_1 points at measured Q^2
- NLO QCD fit ($\overline{\mathrm{MS}}$) to world data:

$$\Delta\Sigma = 0.202^{+0.042}_{-0.077} \quad \Longrightarrow \quad 0.237^{+0.024}_{-0.029} \quad \text{at } Q^2 = 4 \text{ GeV}^2$$

Polarised parton distributions

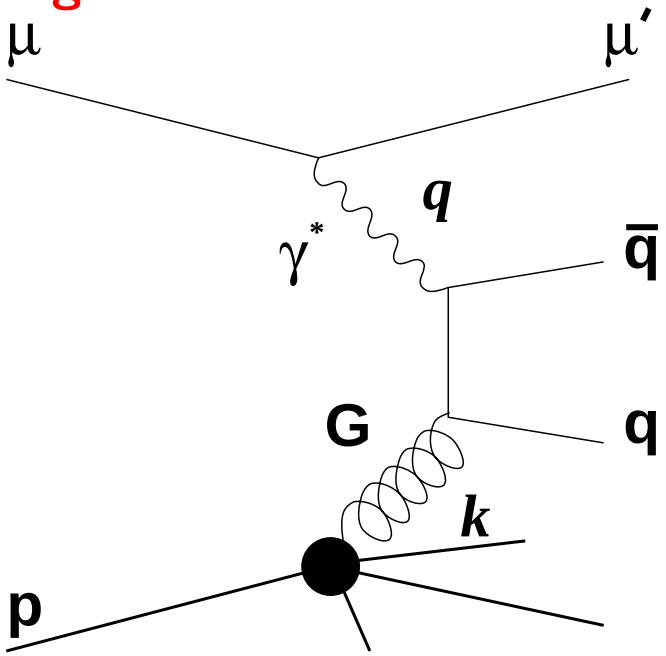


- Recent AAC03 analysis using most of the published data
- Valence quark distributions well determined, antiquark distribution larger errors
- Polarised gluon distribution not determined

Gluon polarisation

$\Delta G/G$ measurement in DIS

- **Photon gluon fusion**



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

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

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

- **Methods**
  - **Open charm production**

    $\gamma g \rightarrow c\bar{c}$
    $\rightarrow D^0 \rightarrow \pi K$ BR: 4%

    scale: m_c^2

    clean channel,
    limited staticstics

  - **High p_T hadron pairs**

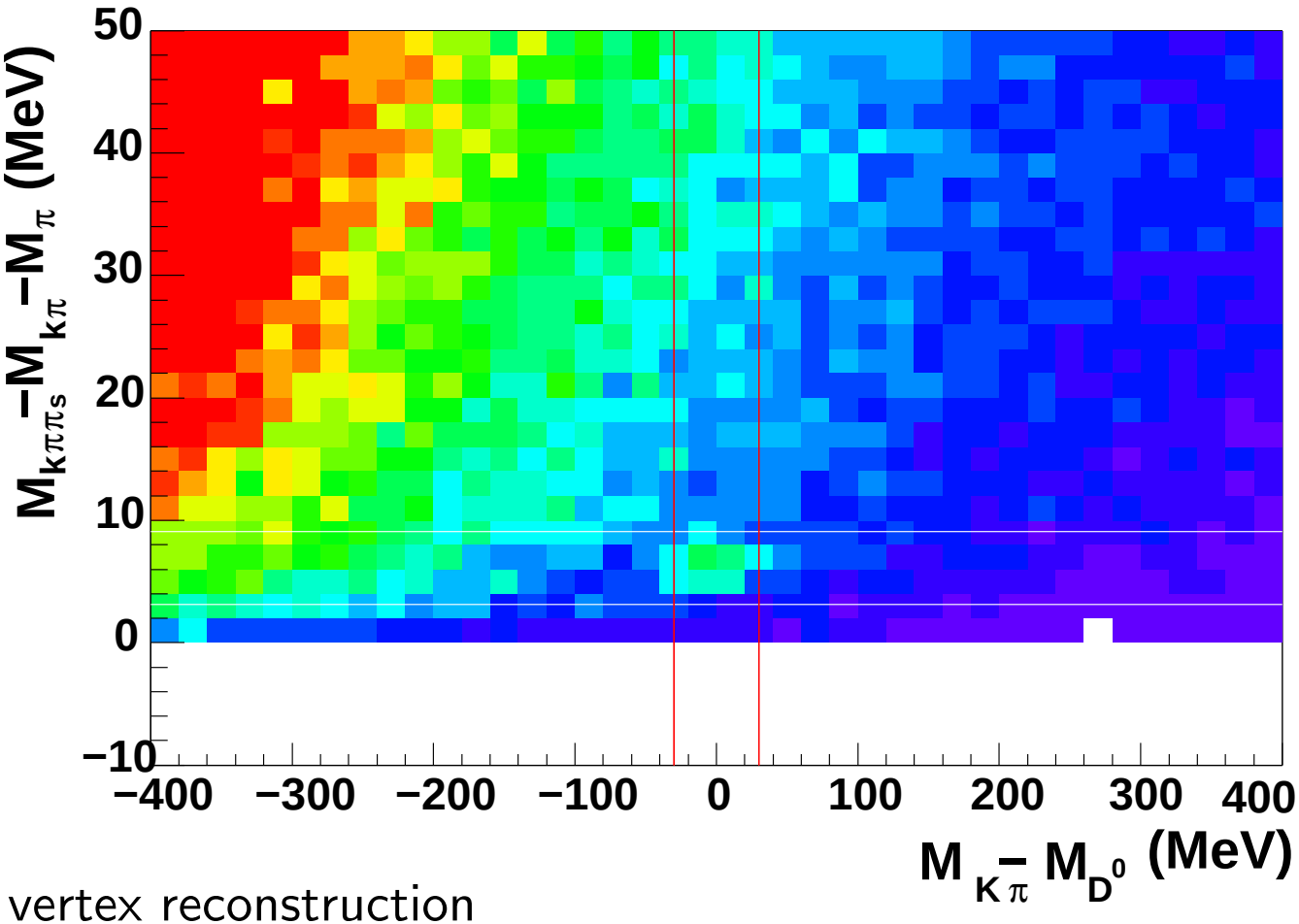
    $\gamma g \rightarrow q\bar{q}$
    $\rightarrow$ 2 jets or H^+H^-

    scale: Q^2 or Σp_T^2

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

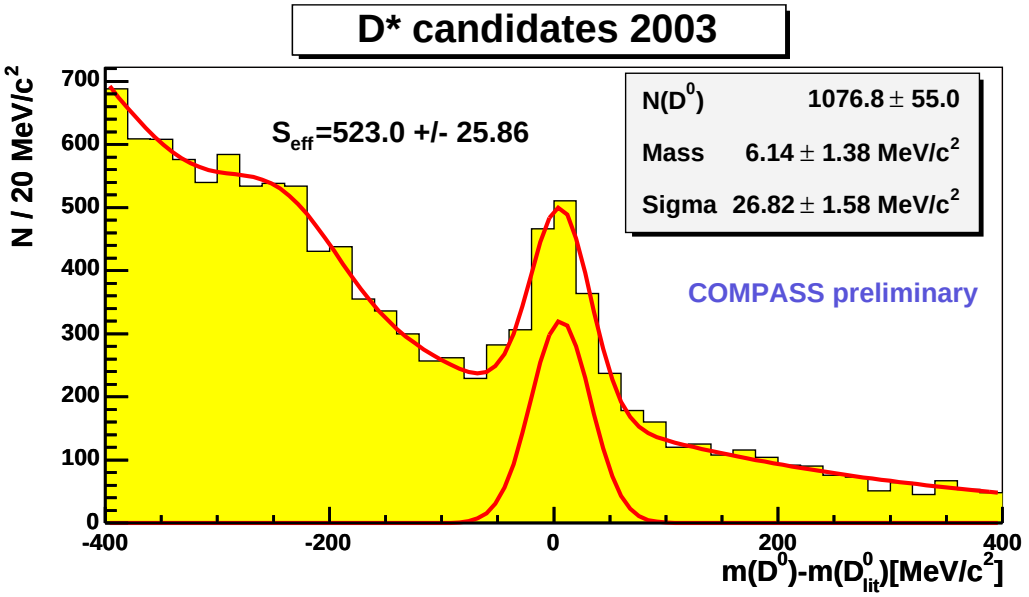
ΔG from open charm

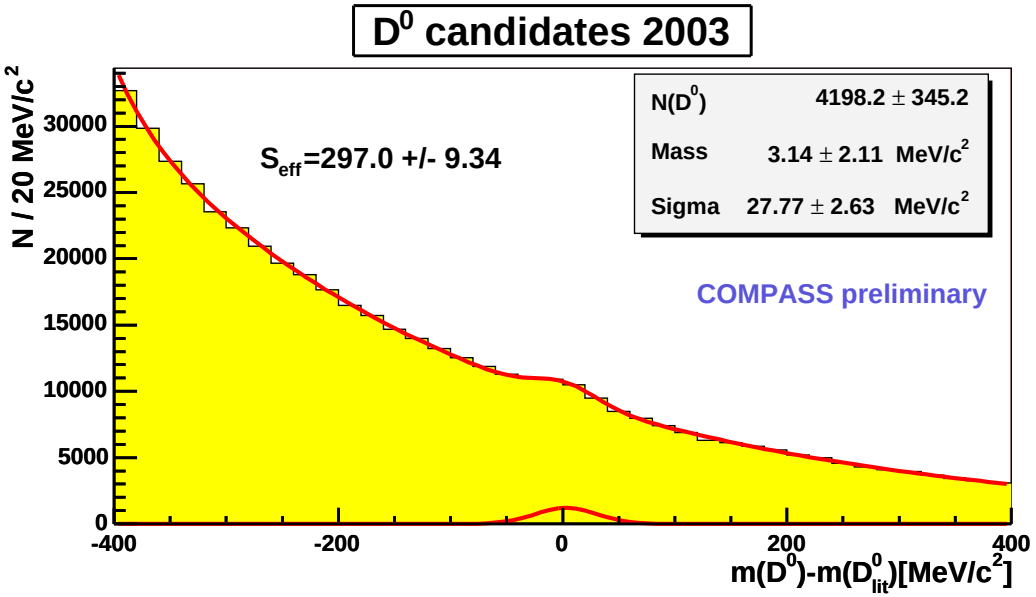
D^* tagging: $D^* \longrightarrow D^0\pi_{\mathrm{slow}} \longrightarrow (K\pi)\pi_{\mathrm{slow}}$



- No decay vertex reconstruction
- Kaon identification by RICH essential
- Cut on mass difference $M_{K\pi\pi} - M_{K\pi} - M_\pi$

Mass spectra





- 1500 D^0 from D^*
- Effective signal

$$S_{\text{eff}} = \frac{S}{1 + S/B}$$

- Experimental asymmmetry

$$A_{\text{exp}} = p_\mu \, p_{\text{T}} \, f \, a_{\text{LL}} \, \frac{S}{S+B} \, \frac{\Delta G}{G}$$

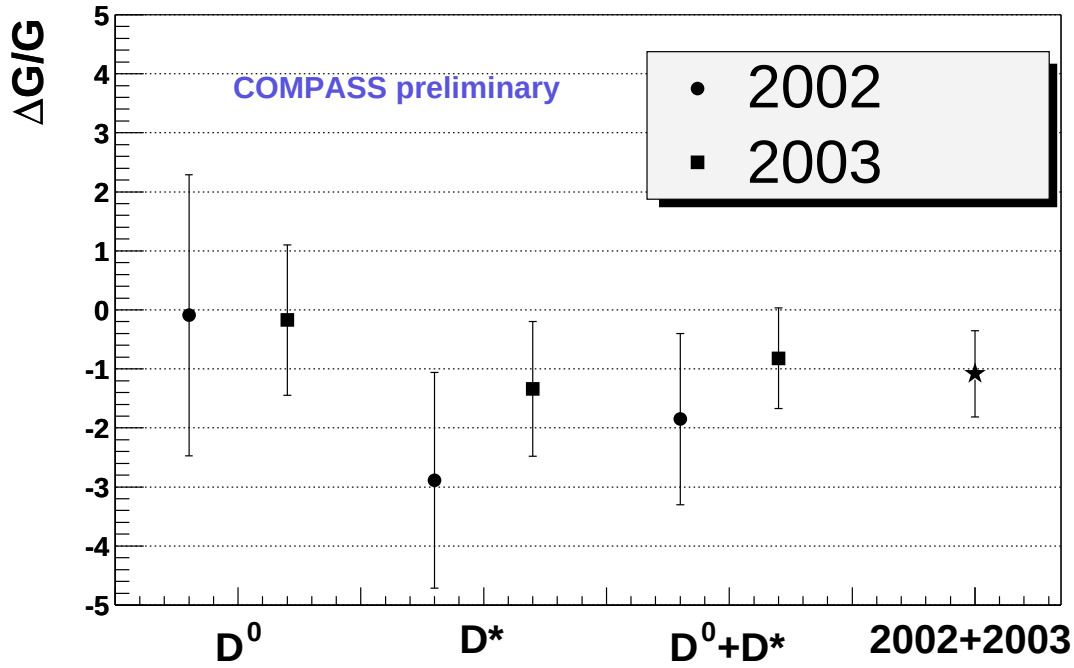
- No physics background

Extraction of $\Delta G/G$

- needs $\langle a_{\mathrm{LL}}^{\mathrm{PGF}} \rangle$ calculated from MC
- AROMA generator
- good description of data distributions by MC
- preliminary result at $\langle x_{\mathrm{g}} \rangle = 0.15$ (RMS: 0.08) from 2002+2003

$$\Delta G/G = -1.08 \pm 0.73\,(\mathrm{stat})$$

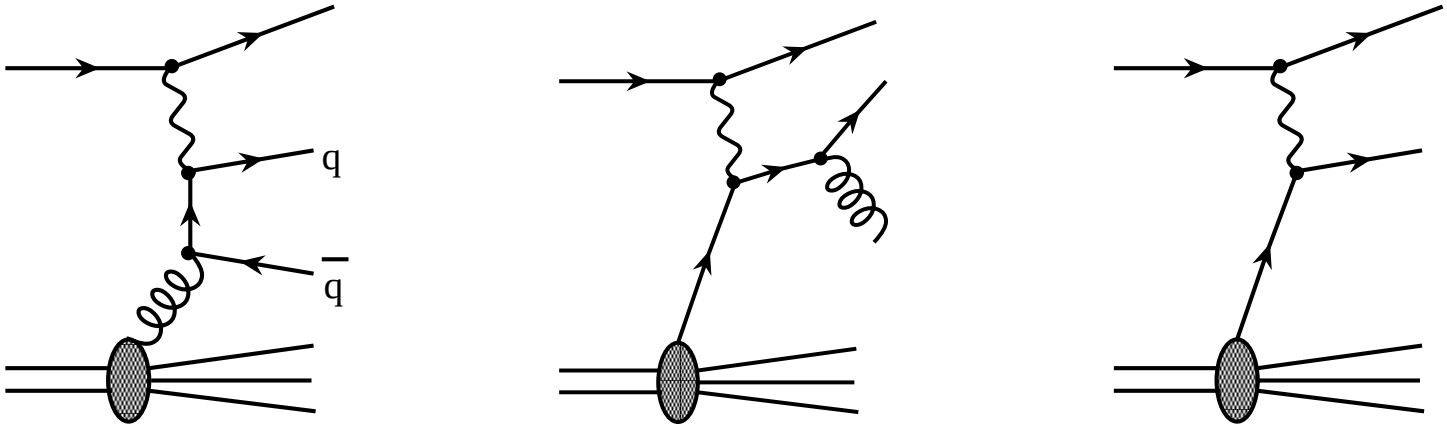
- improvements with 2004 data and additional channels



High p_{T} hadron pairs ($Q^2 > 1$ GeV^2)

- contributions to experimental asymmetry

PGF **QCDC** **LO**



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

- 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}: $p_{\mathrm{T},1}, p_{\mathrm{T},2} > 0.7\,\mathrm{GeV}$ and $p_{\mathrm{T},1}^2 + p_{\mathrm{T},2}^2 > 2.5\,\mathrm{GeV}^2$

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

- 2002/03 data

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

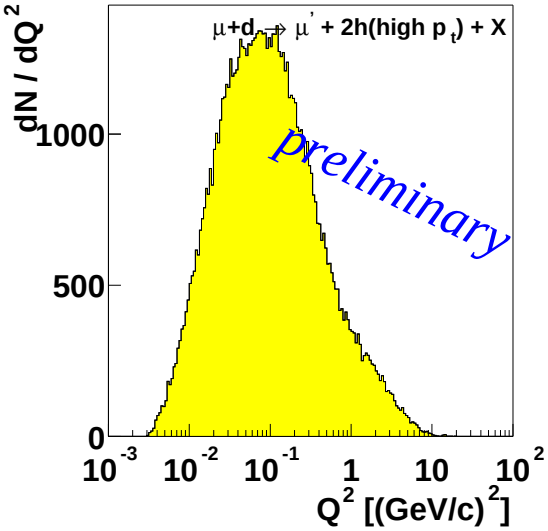
- Monte Carlo sample generated with LEPTO reasonable agreement with data

- additional x cut $\Rightarrow$ $A_1^{\rm d}$ small, LO and QCDC neglected

- $\langle \frac{A_{LL}^{\rm PGF}}{D} \rangle = -0.75 \pm 0.05$
  $R_{\rm PGF} = 0.33 \pm 0.07$, $\langle x_g \rangle = 0.13$ (RMS=0.08)

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

- expectation for 2002-2004: $\delta(\Delta G/G) = 0.22$



- only 10% of statistics at $Q^2 > 1$ GeV^2

- single hadron analysis started

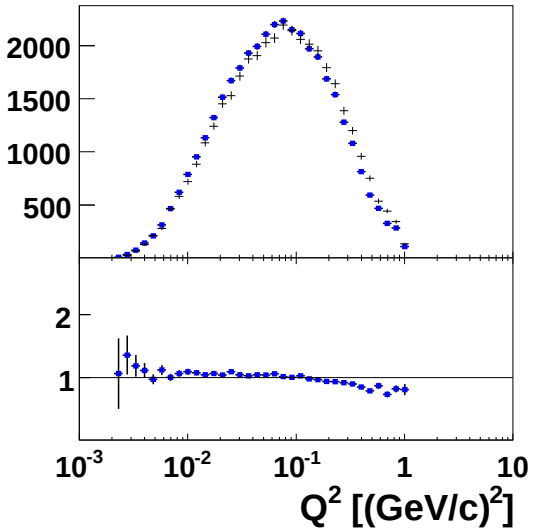
$\Delta G/G$ for $Q^2 < 1$ GeV^2

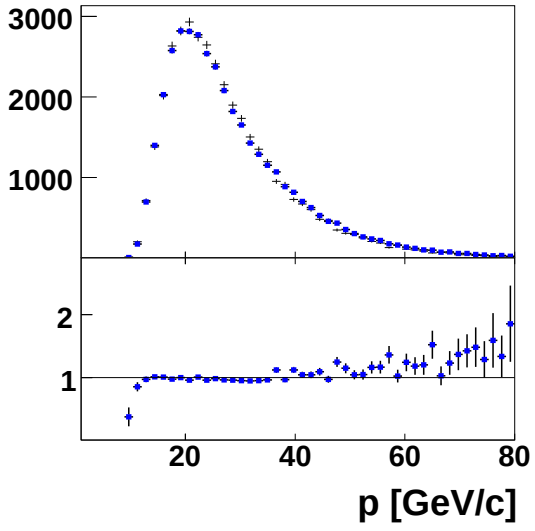
- Much more statistics
  but additional background from resolved photon processes

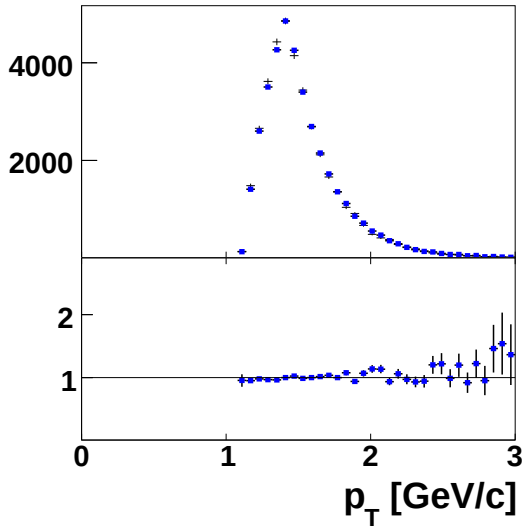
- Data selection same as for large Q^2

$$A_{\parallel}/D = 0.002 \pm 0.019(\text{stat.}) \pm 0.003(\text{syst.})$$

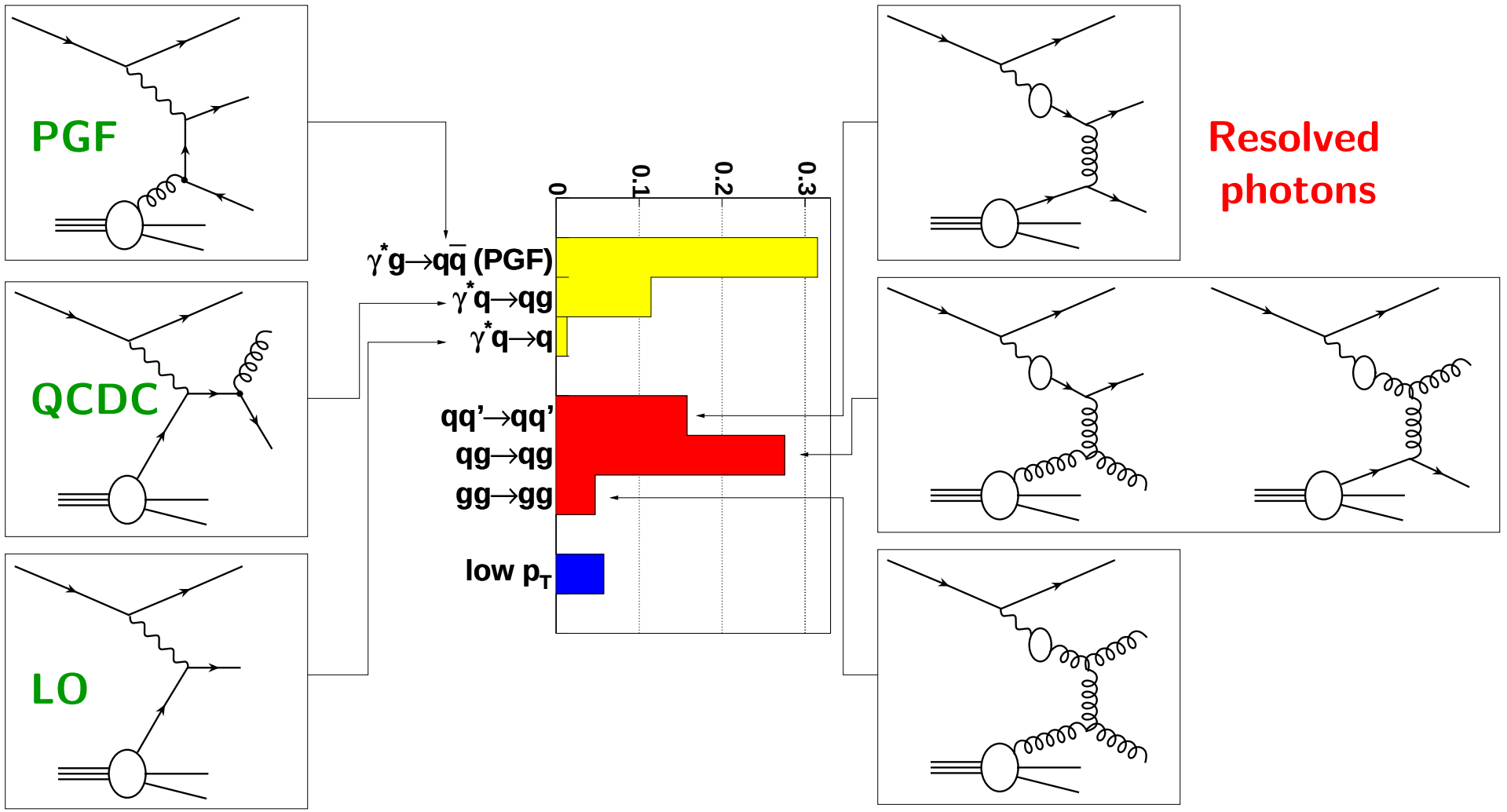
- MC simulation with PYTHIA compared to data (blue points)







Contributions to asymmetry



- LO, low p_{T} neglected

Extraction of $\Delta G/G$

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:

$$-q^{\gamma}_{\mathrm{VMD}} < \Delta q^{\gamma}_{\mathrm{VMD}} < q^{\gamma}_{\mathrm{VMD}}$$

- use as contribution to systematic error

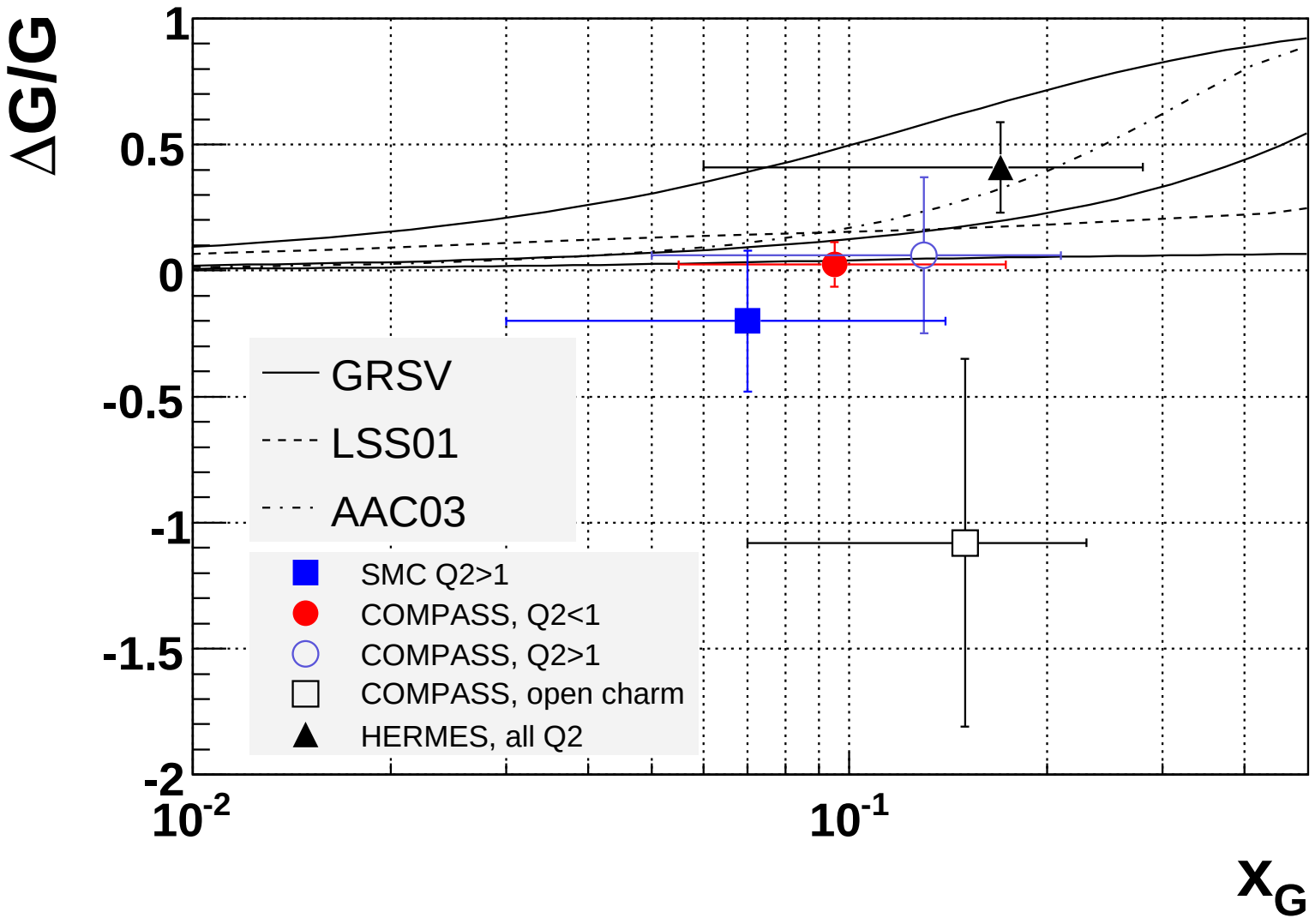
2002/2003 data

- determination of R_{PGF} and a_{LL} from Monte Carlo
- most sensitive parameters in PYTHIA: $k^{\mathrm{N}}_{\mathrm{T}}$ and k^{N}_{γ}

$$\Delta G/G(x_{\mathrm{g}} = 0.095^{+0.08}_{-0.04}, \mu^2 = 3\ \mathrm{GeV}^2) = 0.024 \pm 0.089(\mathrm{stat.}) \pm 0.057(\mathrm{syst.})$$

- systematic error includes exp. syst (0.014)., MC syst.(0.052) and estimate of photon contribution (0.018)
- expectation for 2002-2004: $\delta(\Delta G/G) = 0.05$

$\Delta G/G$ measurements in DIS



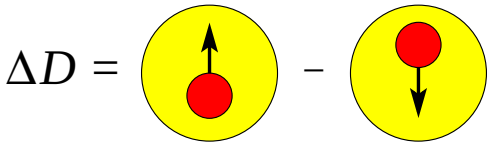
$\Delta G/G$ is small or has a node around $x_{\mathrm{g}} \approx 0.1$

Transversity

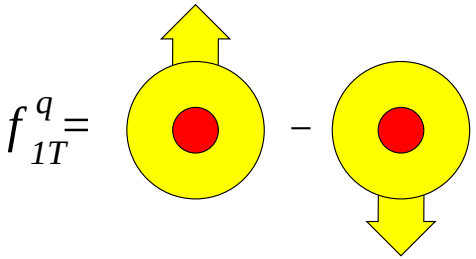
Transversity

- transversity not measurable in inclusive DIS as quark helicity must flip
  $\Rightarrow$ SIDIS
- two methods:

  1) polarisation of struck quark measured by azimuthal asymmetry of produced hadrons
     $\Rightarrow$ **Collins–Effect**



     second contribution: azimuthal asymmetries due to quark transverse momenta
     $\Rightarrow$ **Sivers–Effect**



  2) azimuthal dependence of hadron pair production
     $\Rightarrow$ **interference fragmentation function** $H_1^{\sphericalangle}$

- $\Delta_{\mathrm{T}} D$ and $H_1^{\sphericalangle}$ measurable in e^+e^- collisions $\Longrightarrow$ BELLE

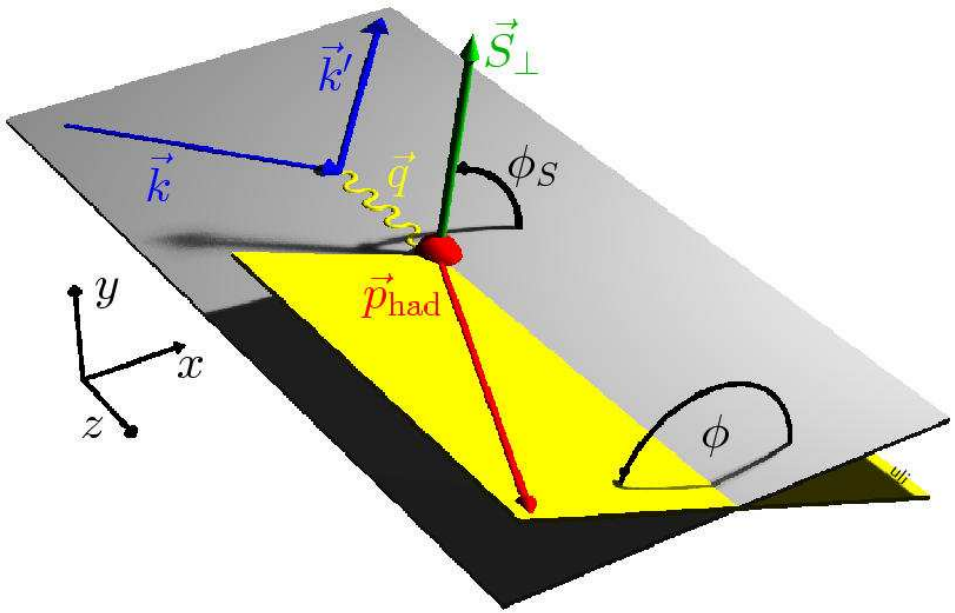
Collins and Sivers effect

Using a transversely polarized target allows to disentangle Collins and Sivers–Effect.

$$A_T^h = \frac{1}{|S_T|}\frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}}$$

$$\sim \ldots \sin(\phi + \phi_s - \pi)\frac{\sum_i e_i^2 \Delta_{\mathrm{T}} q_i(x) \Delta_{\mathrm{T}} D^{\mathrm{h}}_{q_i}(z)}{\sum_i e_i^2 q_i(x) D^{\mathrm{h}}_{q_i}(z)} \qquad \text{Collins–Effect}$$

$$+\ldots \sin(\phi - \phi_s)\frac{\sum_i e_i^2 f_{1T}^{\perp i}(x) D^h_{q_i}(z)}{\sum_i e_i^2 q_i(x) D^h_{q_i}(z)} \qquad \text{Sivers–Effect}$$



- $\Delta_T q(x)$ transversity DF
- $f_{1\mathrm{T}}^{\perp}(x)$ Sivers DF
- $q(x)$ unpolarized DF

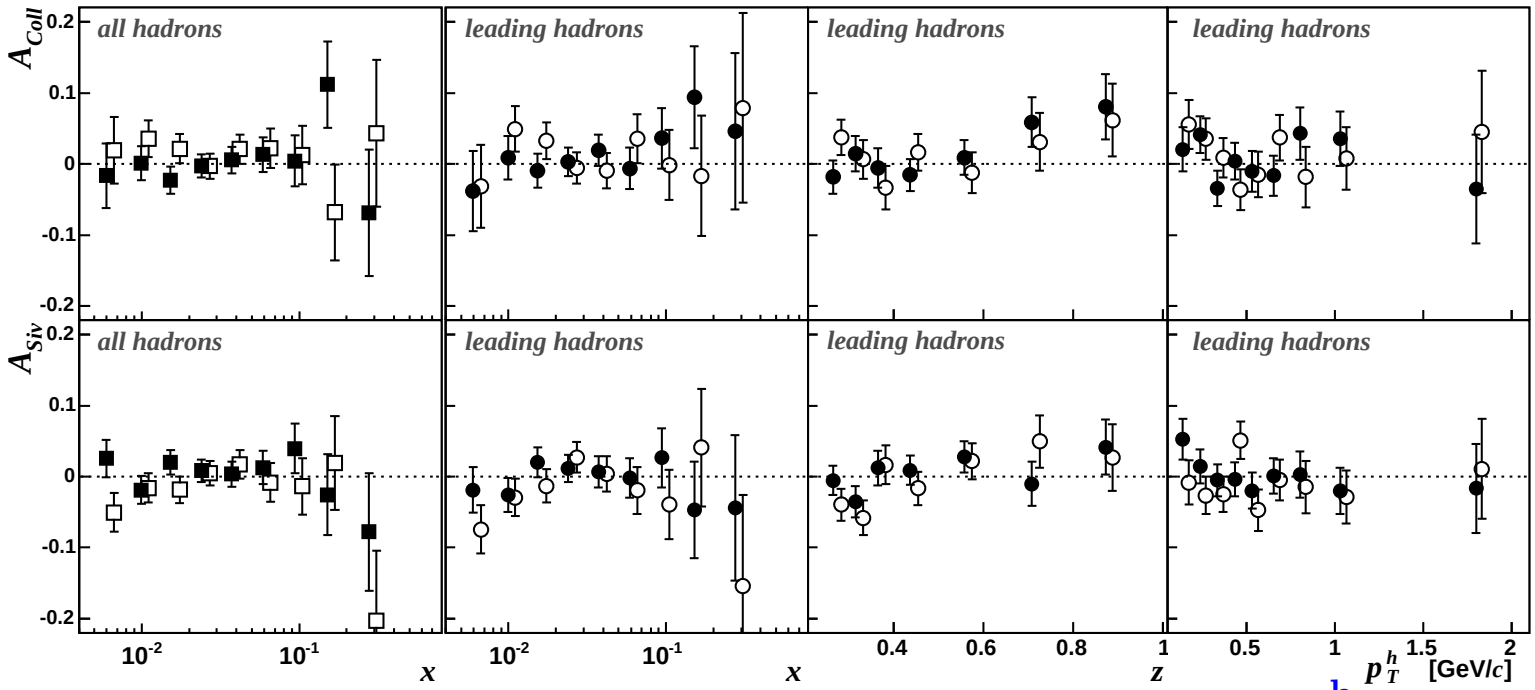
- $\Delta_{\mathrm{T}} D^{\mathrm{h}}_{\mathrm{q}}(z)$ Collins FF
- $D^{\mathrm{h}}_{\mathrm{q}}(z)$ unpolarized FF

Results for asymmetries

All Hadrons **Leading hadrons**

Collins

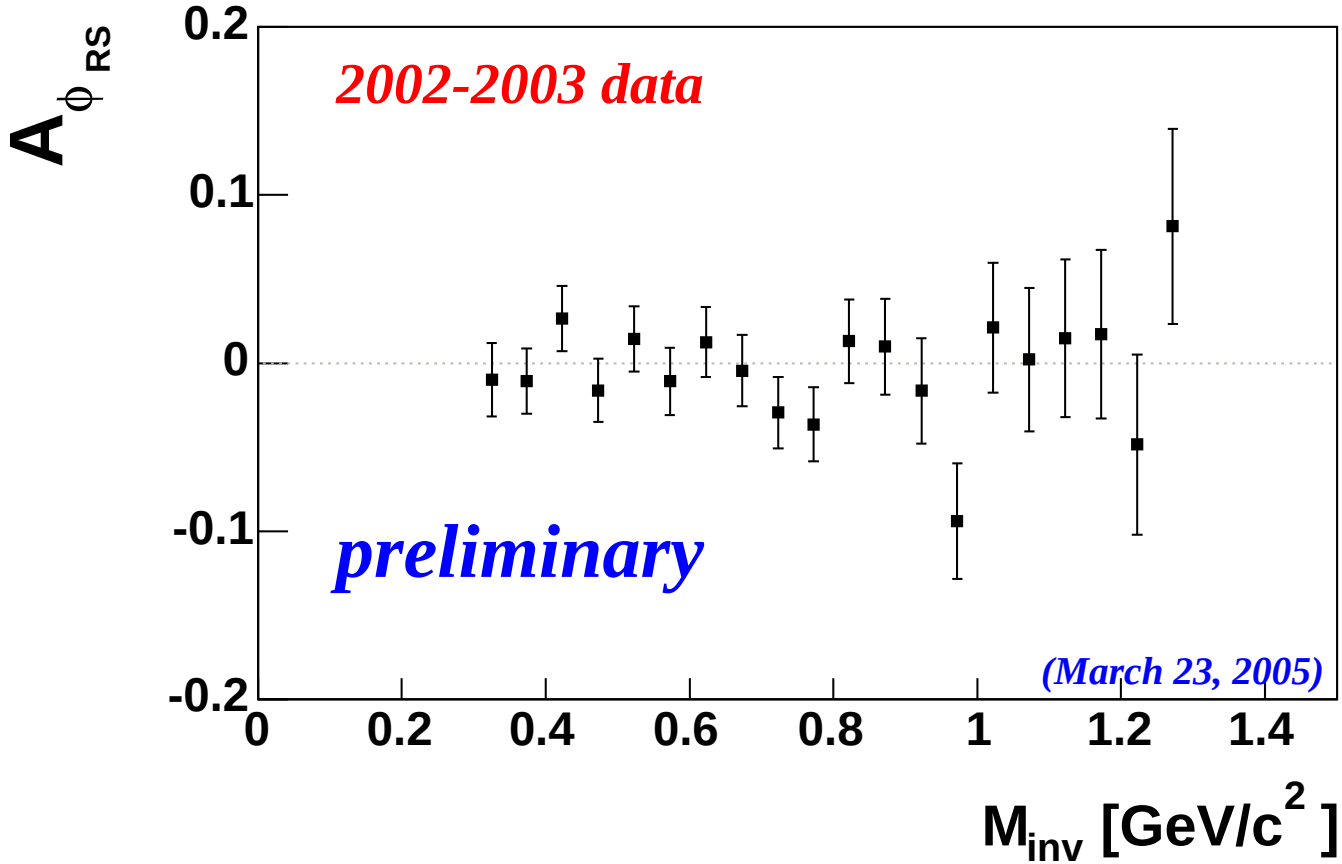
Sivers



x x z p_T^h

- Collins and Sivers asymmetries
  for positive hadrons (closed symbols) and negative hadrons (open symbols)
- asymmetries small: cancellation in deuteron?
- more statistics from 2003 and 2004, proton target (NH_3) in 2006

Two hadron asymmetries



- results from 2002/2003
- $A_{\Phi_{\mathrm{RS}}} \sim \sum_i e_i^2 \Delta_{\mathrm{T}} q_i(x) H_{1q_i}^{\sphericalangle \mathrm{h}}(z)$
- asymmetry vs. M_{inv}, x, z on deuterons consistent with 0

Summary

- Many new results from COMPASS from 2002 and 2003 data
- Gluon polarisation measured with several methods
  $\Rightarrow$ more statistics needed
- New precise data for the longitudinal spin structure function at small x
  $\Rightarrow$ improvement of polarised PDFs
- Two methods to determine transversity
- More results on semi-inclusive DIS, ρ meson production, Λ polarisation
- Exploratory run in 2004 for Primakoff reactions $\Rightarrow$ analysis going on
- Plans:
  - more data ($>$ factor 2) from 2004
  - data taking continues in 2006, ^{6}LID for longitudinal polarisation, NH_3 for transverse polarisation
  - new target solenoid $\Longrightarrow$ larger hadron accepatance
  - improvement of RICH (electronics, photon detection)
  - next hadron run probably 2007