Gluon contribution to the Sivers effect. COMPASS results on deuteron data.

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Outline

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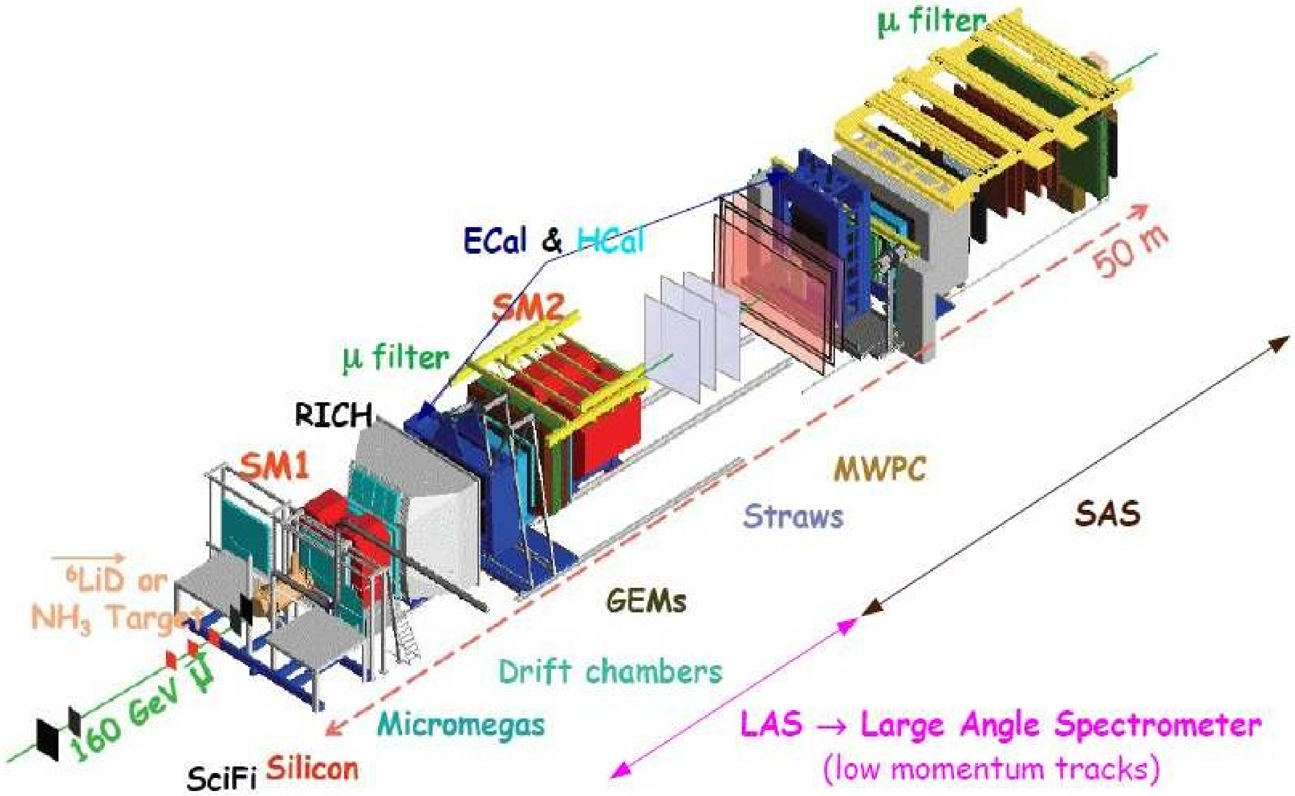
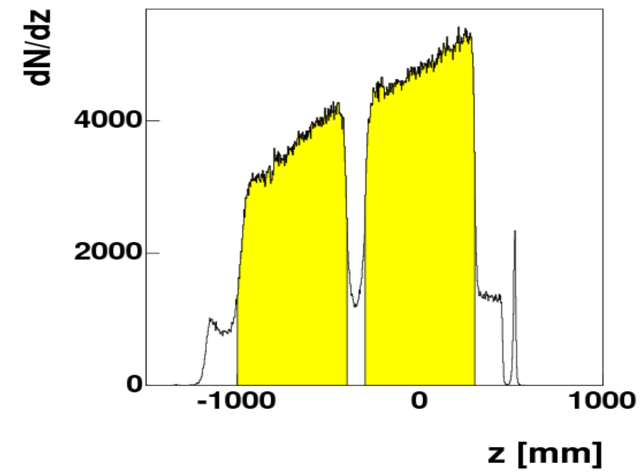
Motivation

1. The Sivers effect for gluons is connected to the gluon orbital angular momentum (OAM) which may be the missing part of nucleon spin structure
2. For the first time we extract the Sivers effect for gluons
3. Selection of high-p_T hadron pair sample enhances the fraction of photon-gluon-fusion (PGF) in the sample

The COMPASS experiment

The COMPASS experiment

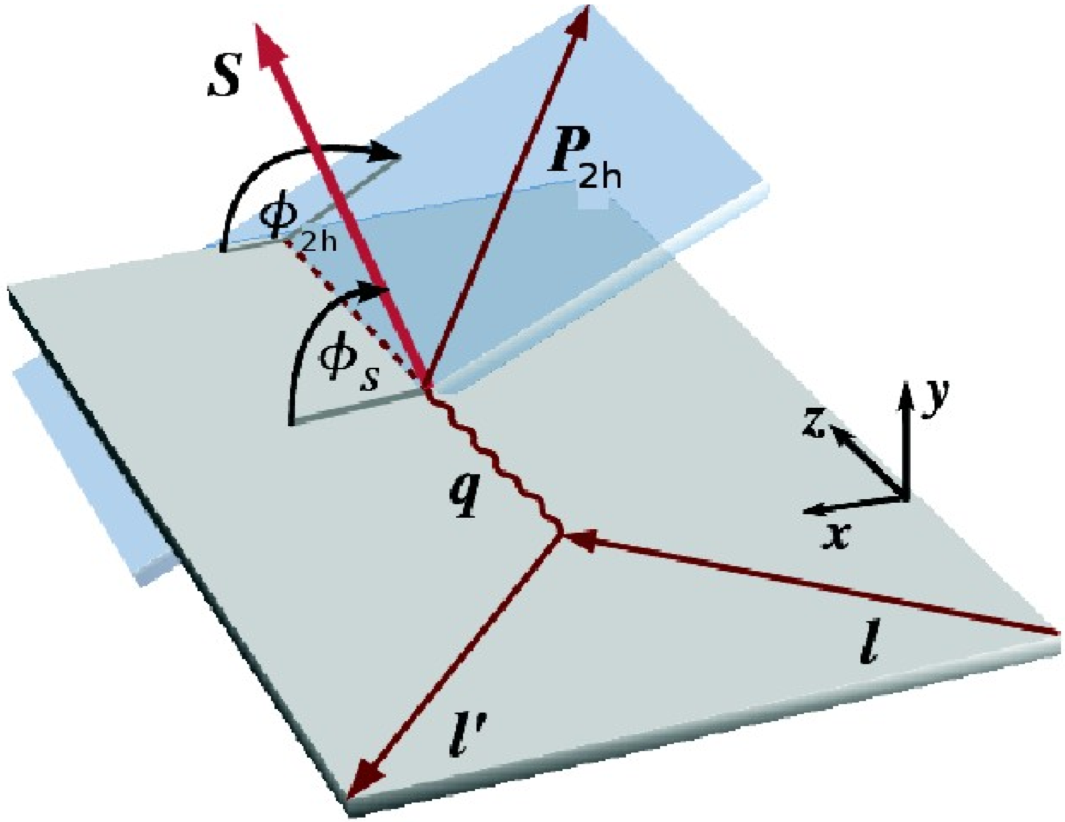




^{6}LiD target dilution factor:
$\langle f \rangle \approx 0.40$
Polarisation:
$\langle P_T \rangle \approx 0.50$

- 2 stage spectrometer with tracking, calo and PID
- Longitudinally polarised beam 160 GeV/*c* μ^+
- Transversely polarised deuteron target (^{6}LiD)
- Target polarisation reversed every week via microwave and adiabatic rotation

Azimuthal angles

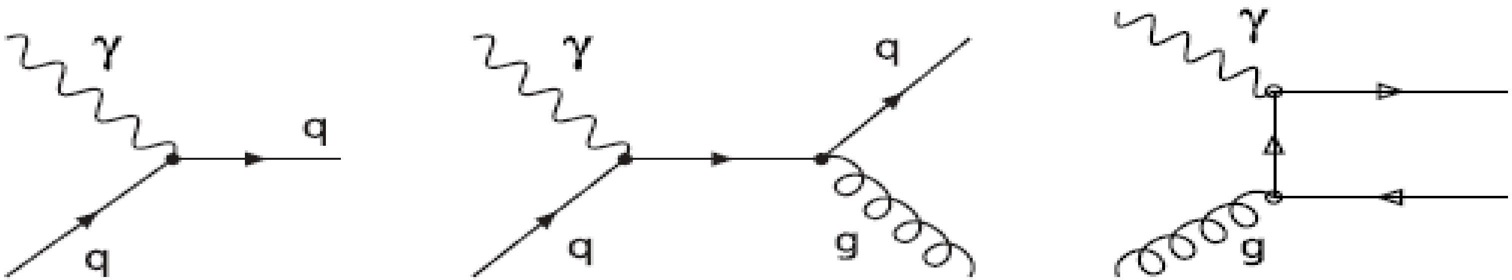


$\mathbf{P}_{2h} = \mathbf{p}_1 + \mathbf{p}_2$

Sivers angle:

$\phi = \phi_{2h} - \phi_S$

The 3 processes



LP **QCDC** **PGF**

$$A_{UT}^{\sin(\phi_{2h}-\phi_s)} = R_{PGF} A_{PGF}^{\sin(\phi_{2h}-\phi_s)}(< x_G >) + R_{LP} A_{LP}^{\sin(\phi_{2h}-\phi_s)}(< x_{Bj} >)$$
$$+ R_{QDCD} A_{QCDC}^{\sin(\phi_{2h}-\phi_s)}(< x_C >)$$

The choice of high-p_T hadron pair sample enhances the fraction of PGF (R_{PGF}).

weighted method

The method is applied in a similar way as in COMPASS open-charm analysis of Δg/g extraction.

All variables can be labeled as a vector:

$$\vec{x} = (x_{Bj}, y, t, \phi, ...)$$

The number of events is given by:

$$n_c(\vec{x}) = \alpha_c(\vec{x})(1 + \beta_c(\vec{x})A(\vec{x}))$$

$$c = u, d, u', d'$$

$$\alpha_c(\vec{x}) = a_c \Phi n_c \sigma$$

Instead of normal sum we weight every event by ω:

$$p_c = \int \omega(\vec{x}) n_c(\vec{x}) d\vec{x} = \sum_{i=1}^{N_c} \omega_i = \tilde{\alpha}_c (1 + \{\beta_c\}_\omega \{A\}_{\beta_c \omega})$$

$$\{\eta\}_\omega = \frac{\int \eta \omega \alpha_c d\vec{x}}{\int \omega \alpha_c d\vec{x}} \qquad \tilde{\alpha}_c = \int \alpha_c \omega d\vec{x}$$

weighted method

Assuming A is linear in x and independent of other variables:

$$p_c = \int \omega(\vec{x}) n_c(\vec{x}) d\vec{x} = \sum_{i=1}^{N_c} \omega_i = \tilde{\alpha}_c (1 + \{\beta_c\}_\omega A(< x >))$$

$$< x > \equiv \{x\}_{\beta_c \omega}$$

$$\{\beta_c\}_\omega = \frac{\int \beta_c \omega \alpha_c d\vec{x}}{\int \omega \alpha_c d\vec{x}} = \frac{\sum_{i=1}^{N_c} \beta_i \omega_i}{\sum_{i=1}^{N_c} \omega_i}$$

In our case we have:

$$\omega = f \sin\phi \qquad \beta_c = P_T f \sin\phi$$

$$\boxed{\tilde{\alpha}_c = \int \omega(\vec{x}) \alpha_c(\vec{x}) d\vec{x}} \qquad \frac{\tilde{\alpha}_u \tilde{\alpha}_{d'}}{\tilde{\alpha}_d \tilde{\alpha}_{u'}} = 1$$

weighted method

3 processes:

$$\sum_{i=1}^{N_c} \omega_i^G = \tilde{\alpha}_c^G [1 + \{\beta_c^G\}_{\omega^G} A_{PGF}^{\sin(\phi_{2h}-\phi_s)}(< x_G >) + \{\beta_c^L\}_{\omega^G} A_{LP}^{\sin(\phi_{2h}-\phi_s)}(< x_{Bj} >)$$
$$+ \{\beta_c^C\}_{\omega^G} A_{QCDC}^{\sin(\phi_{2h}-\phi_s)}(< x_C >)]$$

$$\sum_{i=1}^{N_c} \omega_i^L = \tilde{\alpha}_c^L [1 + \{\beta_c^G\}_{\omega^L} A_{PGF}^{\sin(\phi_{2h}-\phi_s)}(< x_G >) + \{\beta_c^L\}_{\omega^L} A_{LP}^{\sin(\phi_{2h}-\phi_s)}(< x_{Bj} >)$$
$$+ \{\beta_c^C\}_{\omega^L} A_{QCDC}^{\sin(\phi_{2h}-\phi_s)}(< x_C >)]$$

$$\sum_{i=1}^{N_c} \omega_i^C = \tilde{\alpha}_c^C [1 + \{\beta_c^G\}_{\omega^C} A_{PGF}^{\sin(\phi_{2h}-\phi_s)}(< x_G >) + \{\beta_c^L\}_{\omega^C} A_{LP}^{\sin(\phi_{2h}-\phi_s)}(< x_{Bj} >)$$
$$+ \{\beta_c^C\}_{\omega^C} A_{QCDC}^{\sin(\phi_{2h}-\phi_s)}(< x_C >)]$$

Minimization:

$$\omega_x = R_x f \sin\phi \qquad \beta_x^c = R_x P_T f \sin\phi$$

$$\chi^2 = (\vec{N} - \vec{f})^T \mathrm{Cov}^{-1} (\vec{N} - \vec{f})$$

$$cov(p_x, p_y) \approx \sum \omega_x \omega_y$$

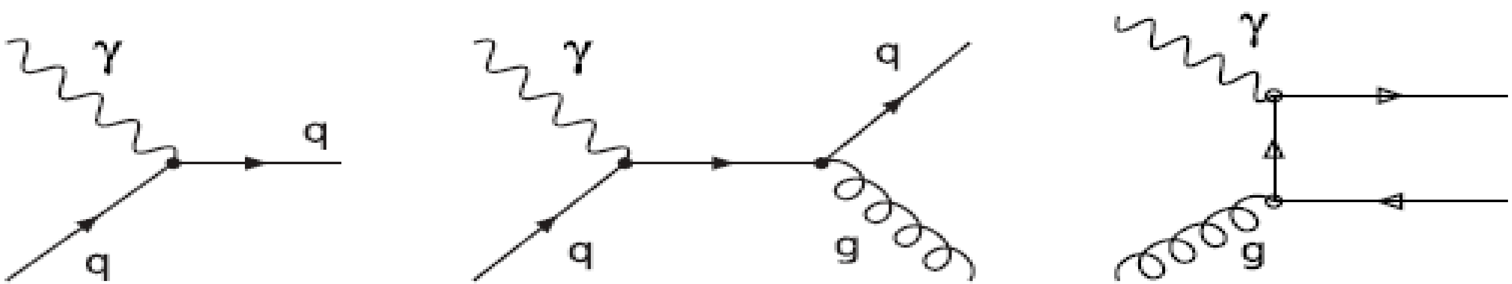
$$\vec{N} = (p_G^u, p_G^d, \ldots, p_C^{u'}, p_C^{d'}) \qquad \vec{f} = (f_G^u, f_G^d, \ldots, f_C^{u'}, f_C^{d'})$$

Neural network approach

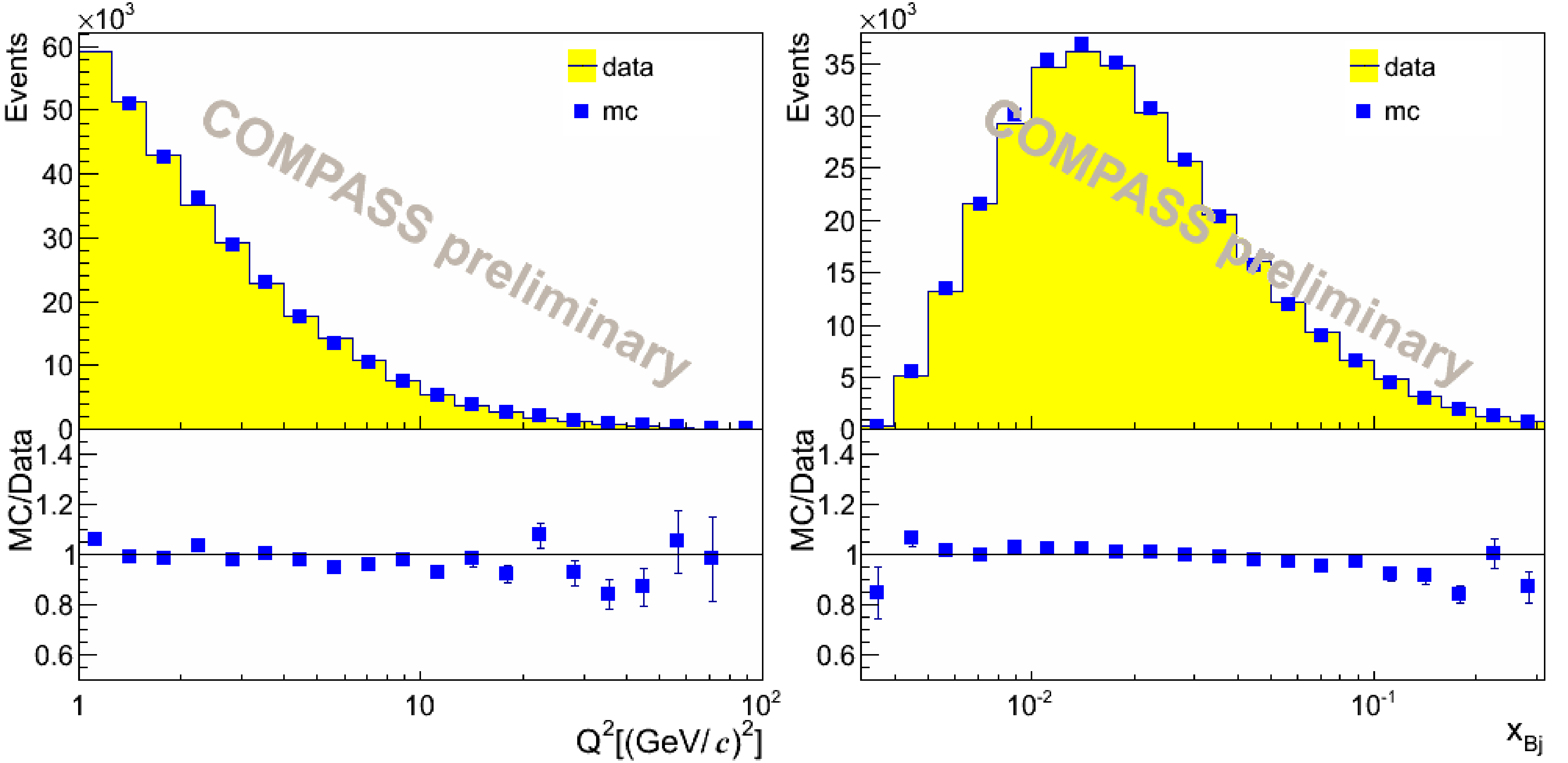
NN trained on MC data (LEPTO + COMGEANT, high-p_T tuning):

p_{T1}, p_{T2}, p_{L1}, p_{L2}, Q^2, x_{Bj}.

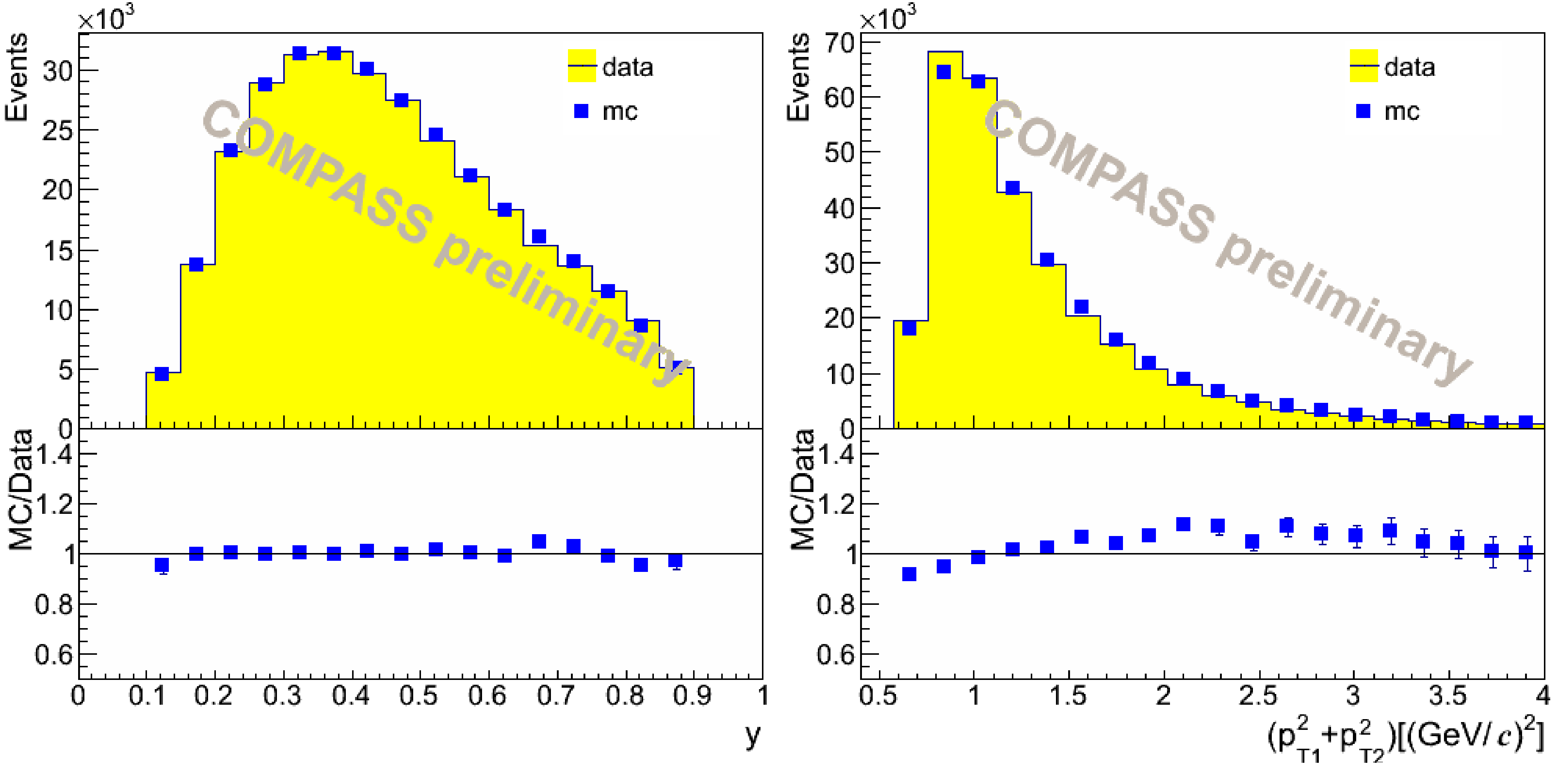
NN output: probabilities (weights) for the 3 subprocesses: LP, QCDC, PGF for every event



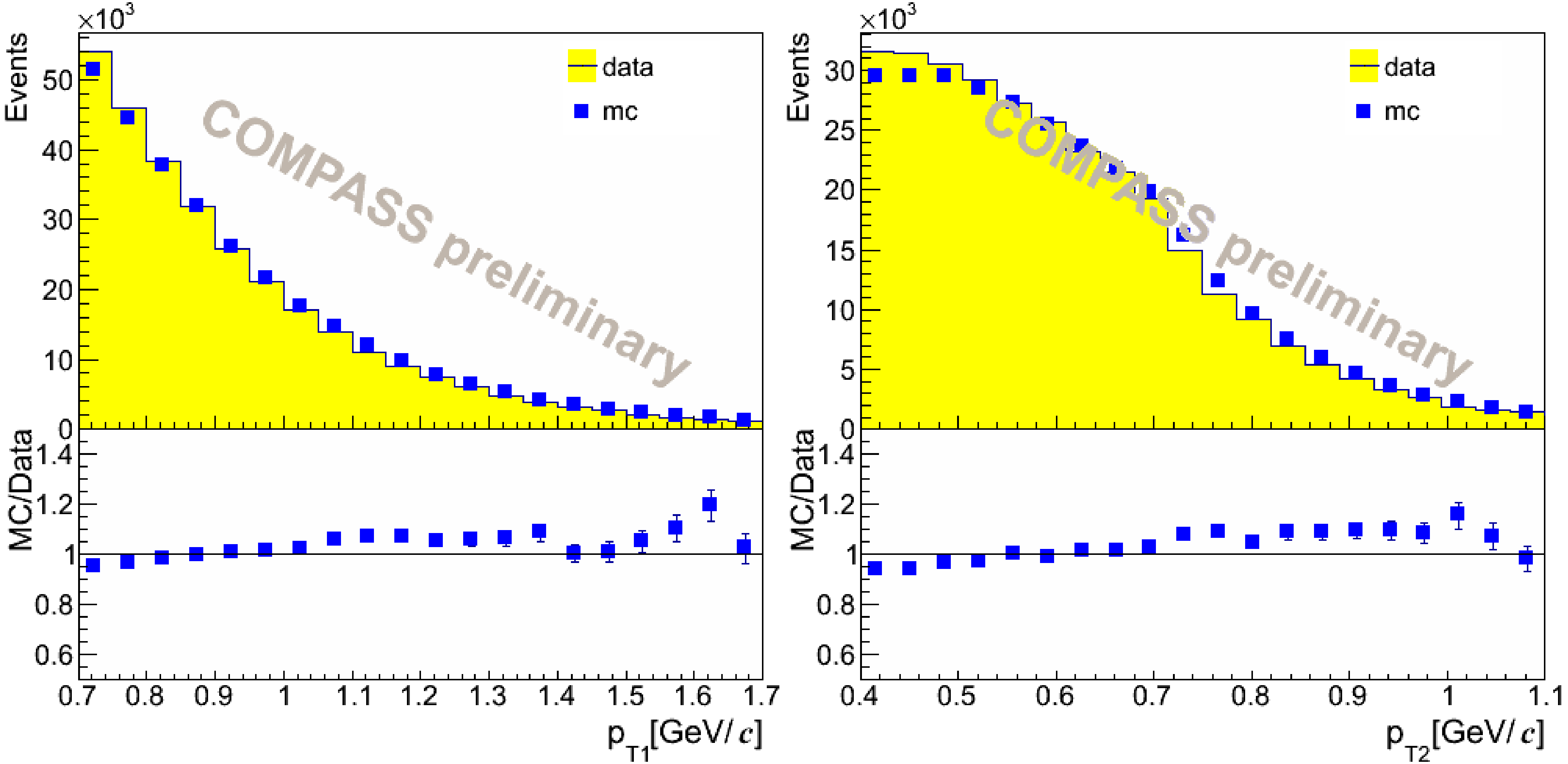
Data vs MC 2004



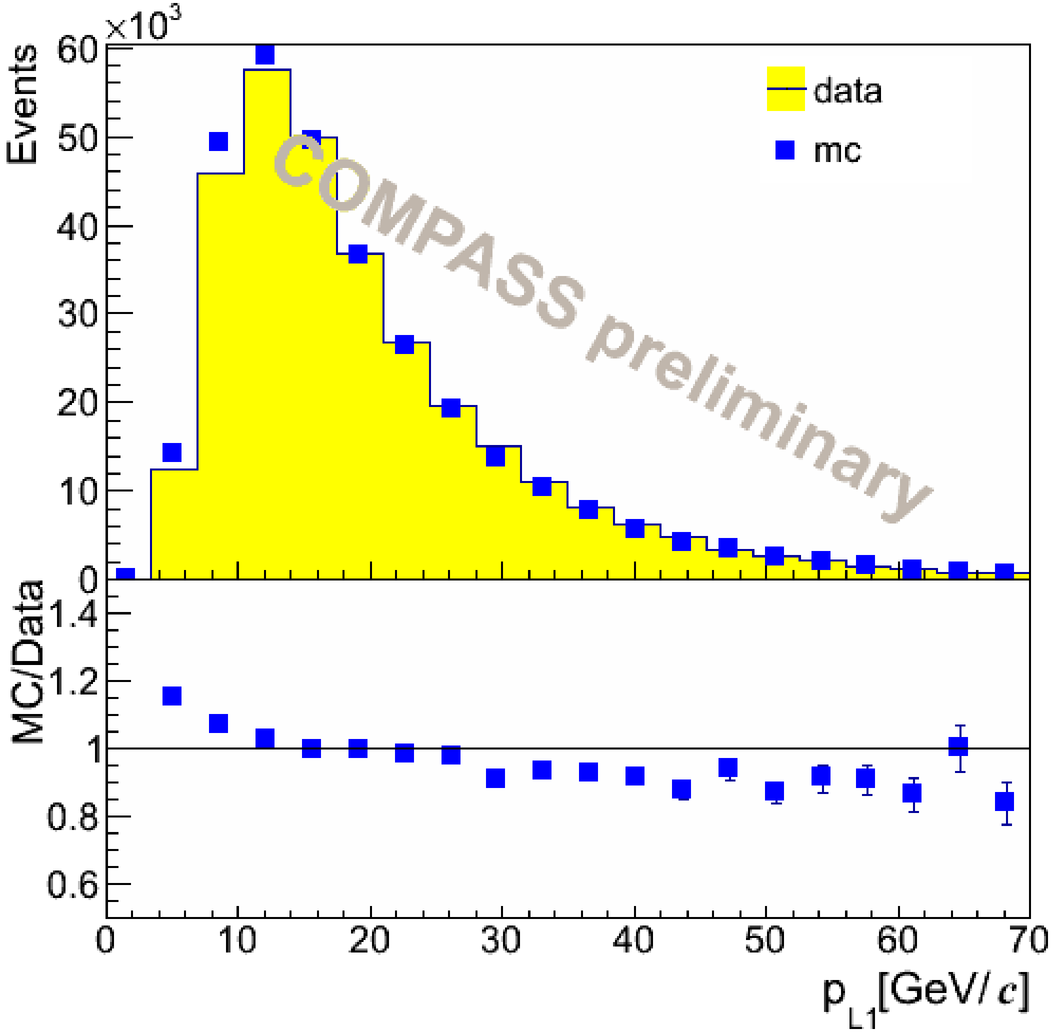
Data vs MC 2004

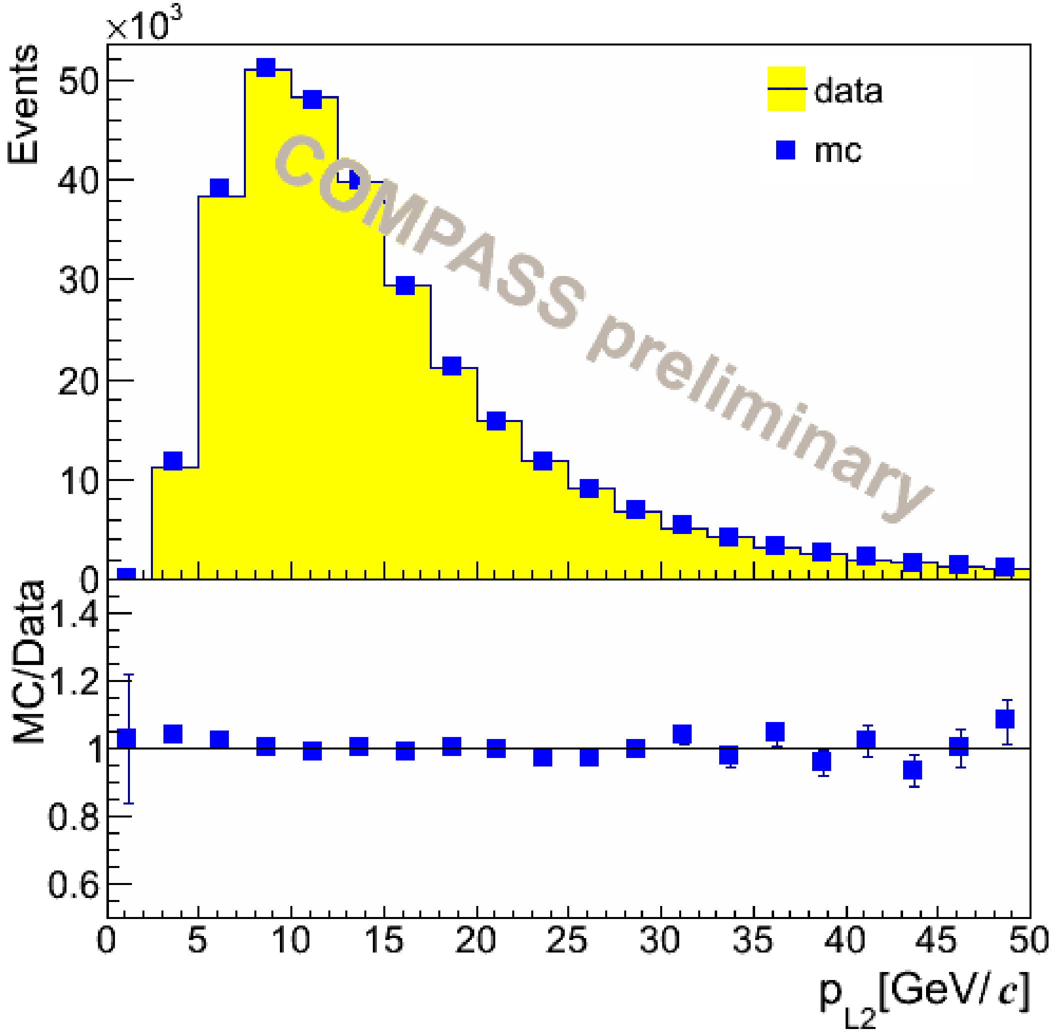


Data vs MC 2004

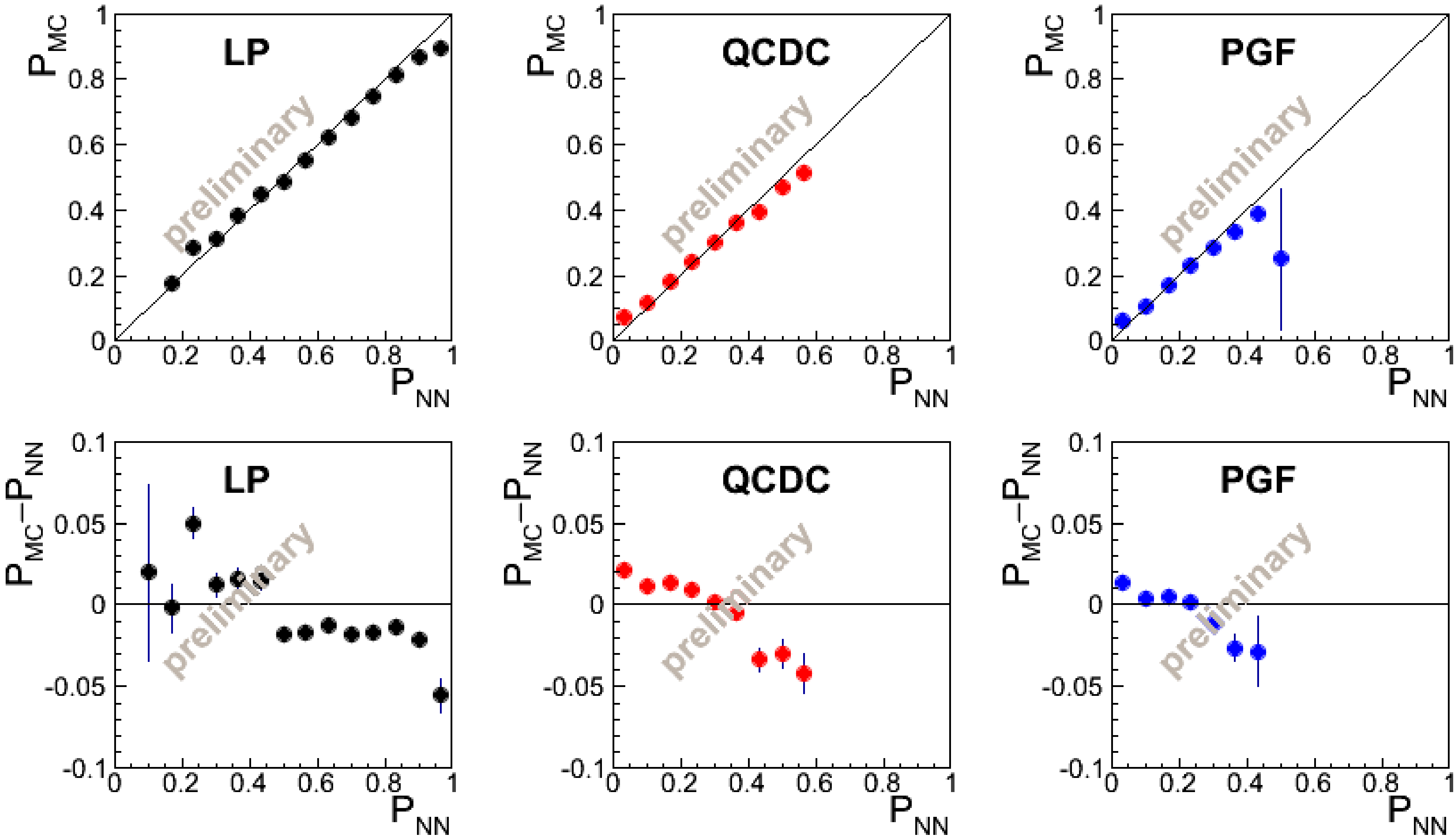


Data vs MC 2004





MC Validation of training of the NN



Validation of the method using Monte Carlo Simulation

- MC (LEPTO + COMGEANT, high-p_T tuning) events have no azimuthal asymmetries therefore we weight every event by $1+A\sin(\phi_{2h} - \phi_S)$.

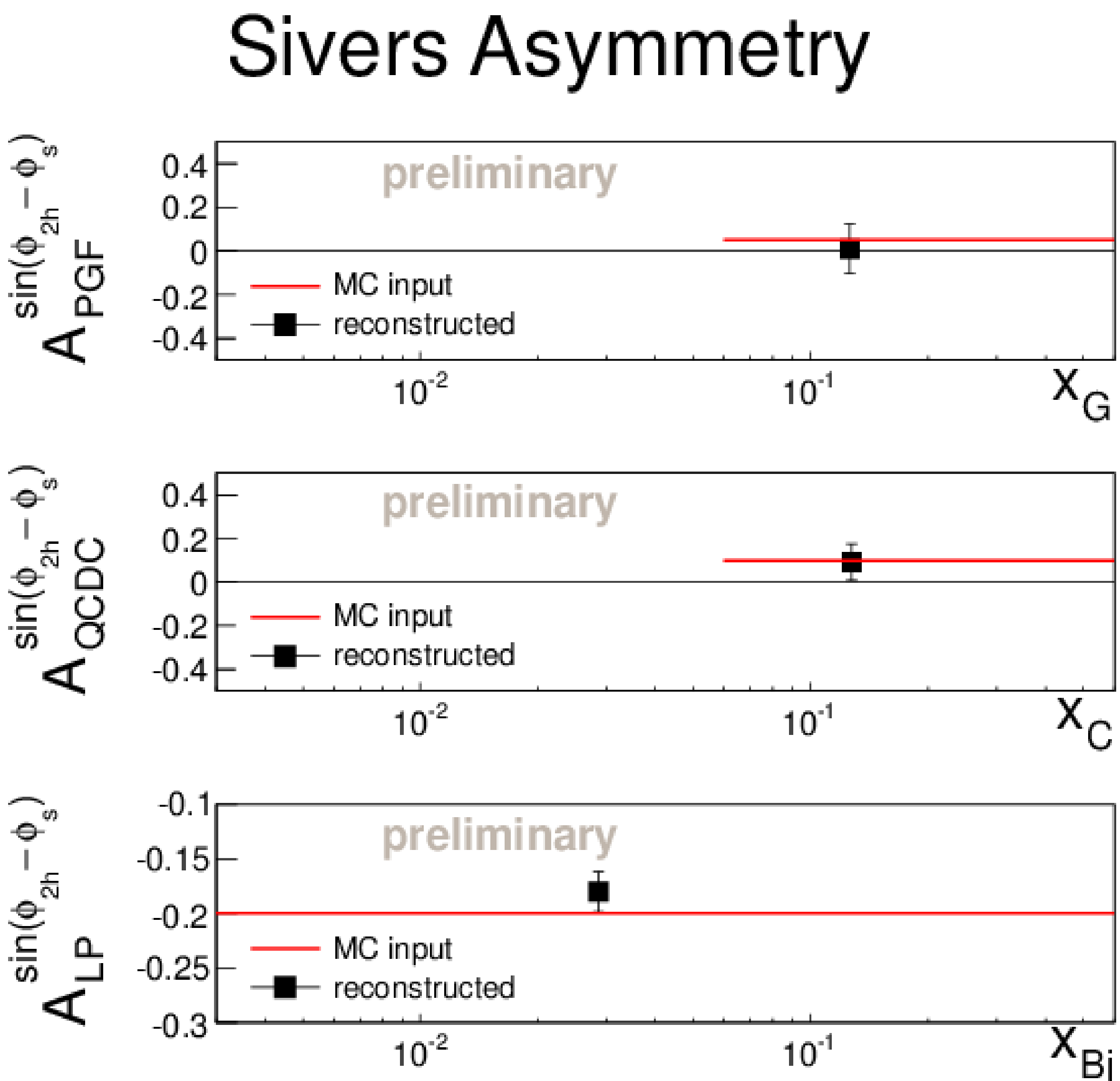
  ϕ_{2h}- azimuthal angle of the vector sum of the 2 leading hadron momenta.

  A- assumed asymmetry different for different processes: (LP, QCDC, PGF).

- For each MC event we get the NN output. fractions :

  R_{LP}, R_{QCDC}, R_{PGF} and x_C, x_G

MC simulation. Validation of the method



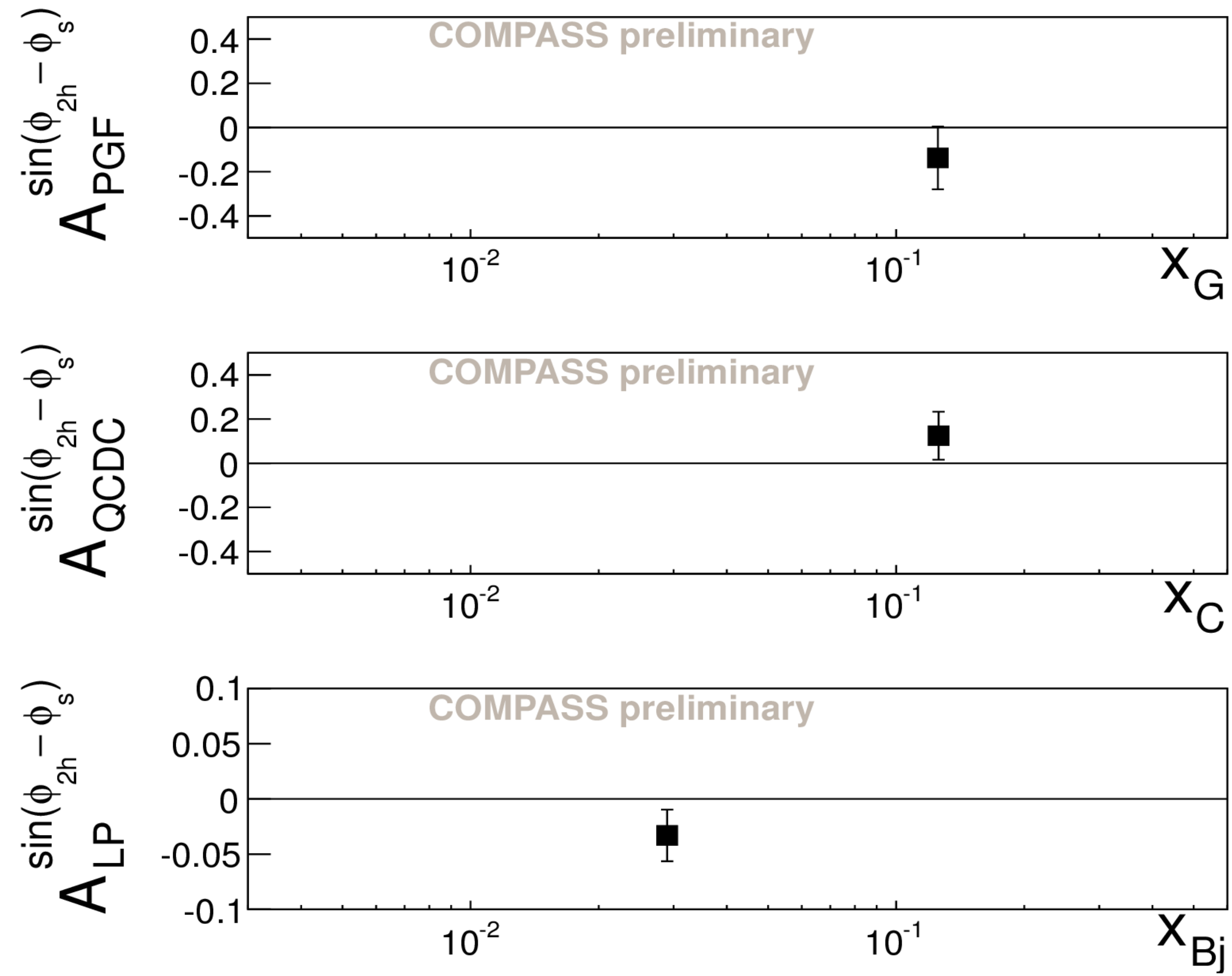
Data selection

COMPASS 2003-2004 data taken on transversely polarised deuteron target.

- Inclusive cuts:
  - $Q^2 > 1 (\mathrm{GeV}/c)^2$
  - $0.003 < x_{Bj} < 0.7$
  - $0.1 < y < 0.9$
- hadronic cuts
  - $p_{T1} > 0.7\ \mathrm{GeV}/c$
  - $p_{T2} > 0.4\ \mathrm{GeV}/c$
  - $z_1 > 0.1$
  - $z_2 > 0.1$

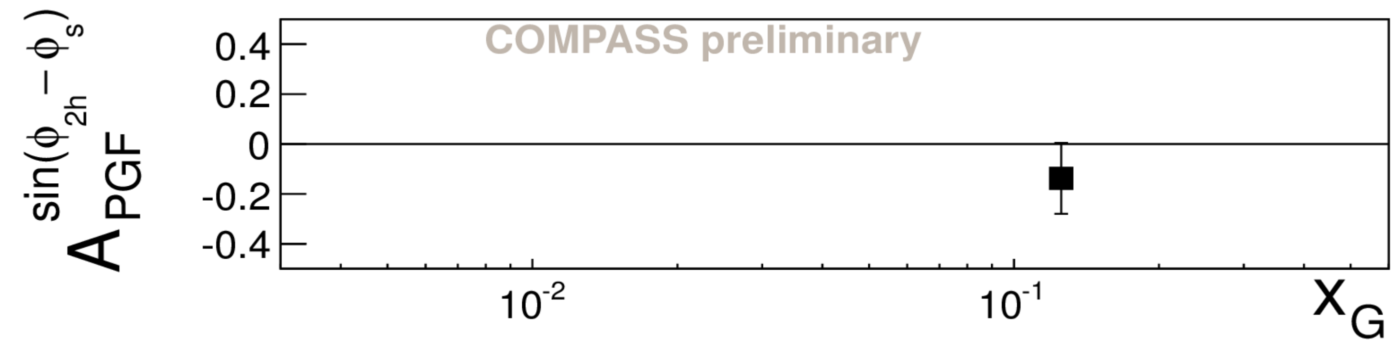
Gluon Sivers results

Sivers Asymmetry

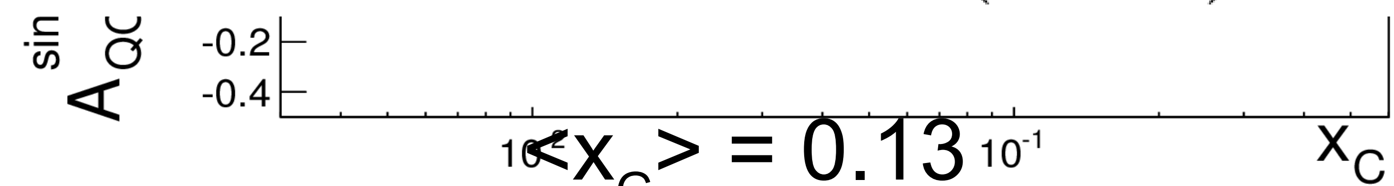


Gluon Sivers results

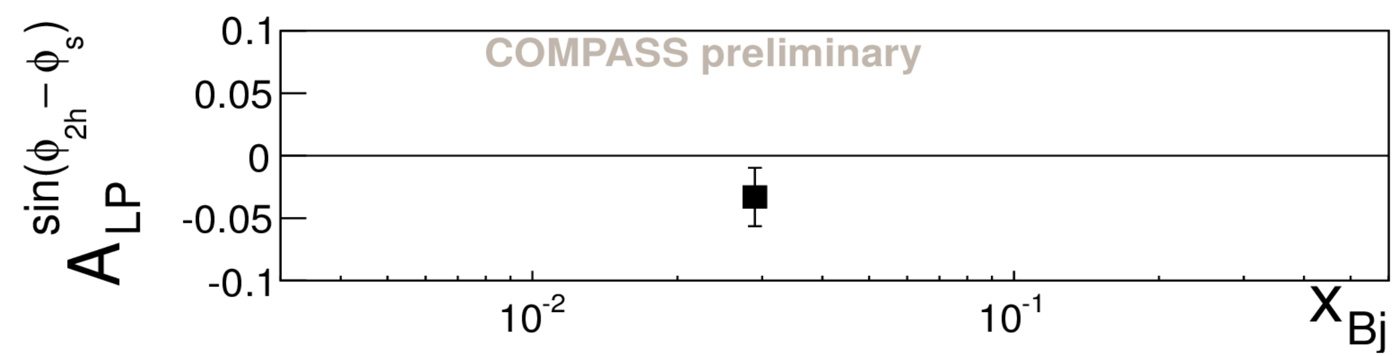
Sivers Asymmetry



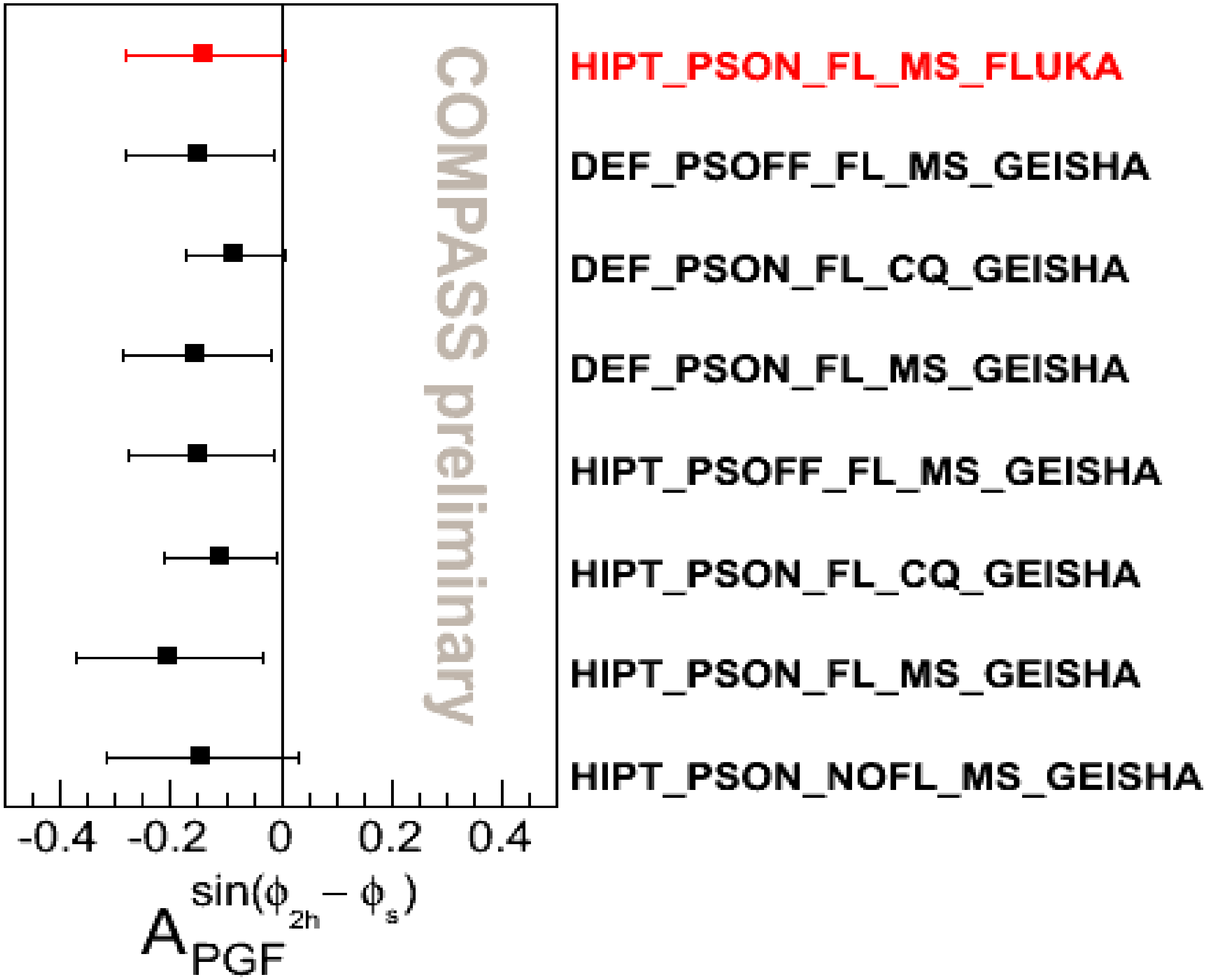
$$\mathbf{A_{PGF}^{\sin(\phi_{2h}-\phi_s)} = -0.14 \pm 0.15(stat.) \pm 0.06(syst.)}$$



$\langle x_G \rangle = 0.13$



Systematics



Summary and outlook

1. First results of the Sivers effect for gluons on deuteron target were obtained by the COMPASS collaboration
2. The result: $\mathbf{A_{PGF}^{\sin(\phi_{2h}-\phi_S)}} = \mathbf{-0.14 \pm 0.15(stat.) \pm 0.06(syst.)}$

   at $\langle x_G \rangle = 0.13$ is compatible with 0
3. The method will be applied to proton transverse data where COMPASS has much larger statistics
4. In parallel the analysis of gluon Sivers via J/Ψ will be performed