The measurement of the gluon Sivers asymmetries in COMPASS at CERN

Luís Silva

LIP - Lisbon

on behalf of the COMPASS Collaboration

September 26th, 2016

SPIN 2016, Champaign-Urbana, IL, USA

Supported by

FCT Fundação para a Ciência e a Tecnologia

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

CERN/FIS-NUC/0017/2015

Motivation

- The Sivers function $f_{1T}^{\perp q}(x, k_\perp^2)$ for 'u' and 'd' quarks has been extensively studied. More information can be found in recent reviews[1] [2].
- What about the gluons?? Is the gluon distribution in the transversely polarised nucleon left-right symmetric? Or do we expect a Sivers effect? This issue has been recently raised in the literature[3] [4].
- $\Rightarrow$ Nevertheless, a nonzero Sivers effect of the gluon can be related to its orbital motion in a polarised nucleon [5]

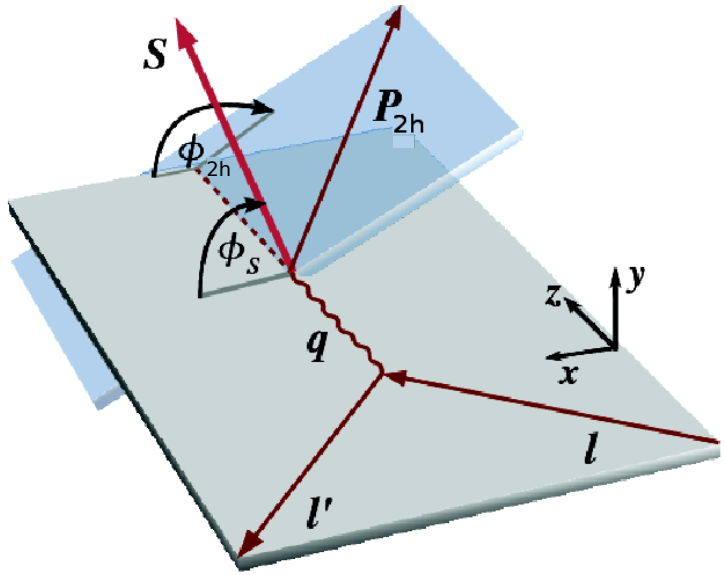
[1] V. Barone *et al.*, Prog. Part. Nucl. Phys., **65**, 267 (2010).
[2] C. A. Aidala *et al.*, Rev. Mod. Phys., **85**, 655 (2013).
[3] P. J. Mulders and J. Rodriguez, Phys. Rev., **D63**, 094021 (2011).
[4] D. Boer *et al.*, Adv. High Energy Phys., 2015, 371396 (2015).
[5] D. W. Sivers, Phys. Rev. D 41, 83 (1990).

Sivers Asymmetry

Sivers Asymmetry:

$$A_T^{2h}(\phi_{\text{Siv}}) = \frac{\Delta\sigma}{\sigma}$$

$$\Delta\sigma = d\sigma^{\uparrow}(\phi_{\text{Siv}}) - d\sigma^{\downarrow}(\phi_{\text{Siv}})$$
$$\sigma = d\sigma^{\uparrow}(\phi_{\text{Siv}}) + d\sigma^{\downarrow}(\phi_{\text{Siv}})$$



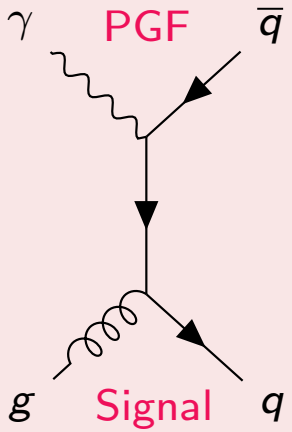
$$\mathbf{P}_{2h} = \mathbf{p}_1 + \mathbf{p}_2$$
$$\phi_{\text{Siv}} = \phi_{2h} - \phi_S$$

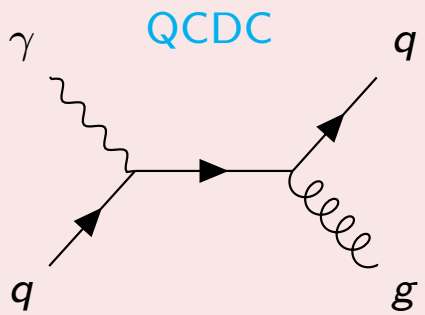
Analysis Method

MC, Weighting Method and Neural Network Approach

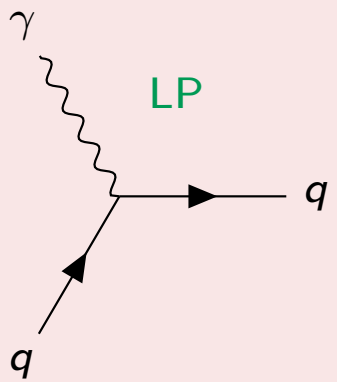
The purpose

- To extract the separated contribution of each of these processes to Sivers asymmetry of 2h SIDIS simultaneously.





Background

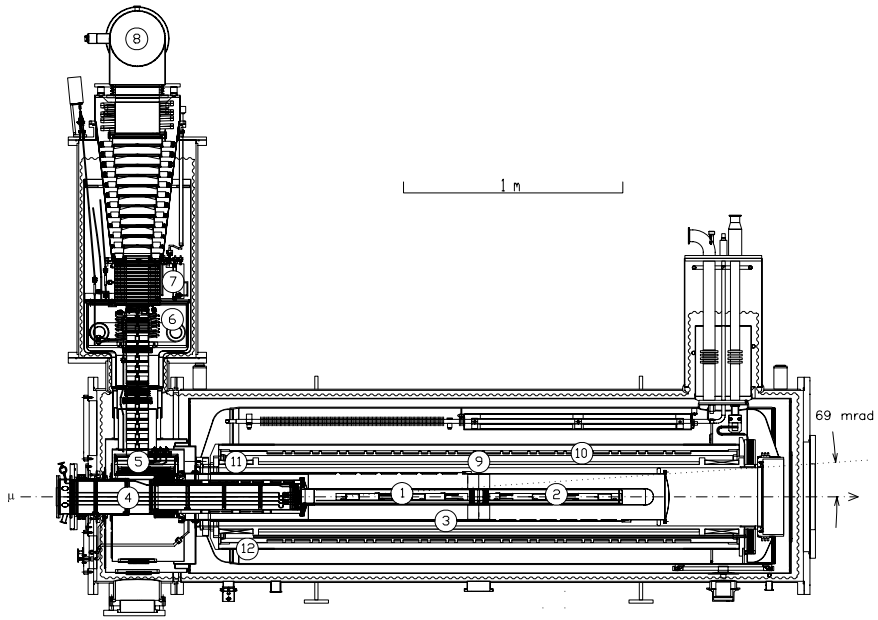


Background

The procedure

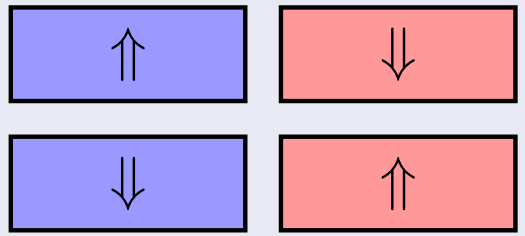
- Select high-p_T hadron pair events to:
  - Enhance the PGF event fraction,
  - Strengthen the correlation between gluon and the high-p_T hadron pair azimuthal angles.
- Estimation of a weight to each process for every event using a Neural Network approach, trained in a MC data sample.
- Extracting the asymmetries solving a equations system by minimisation approach.

How to Access the Asymmetries

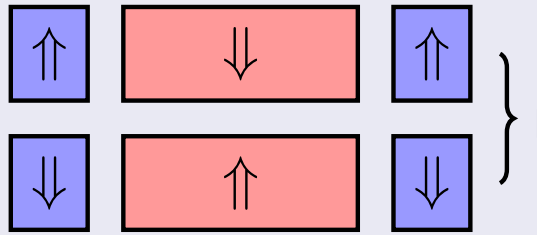


Using different beam and target spin configurations.

2 Cell Target



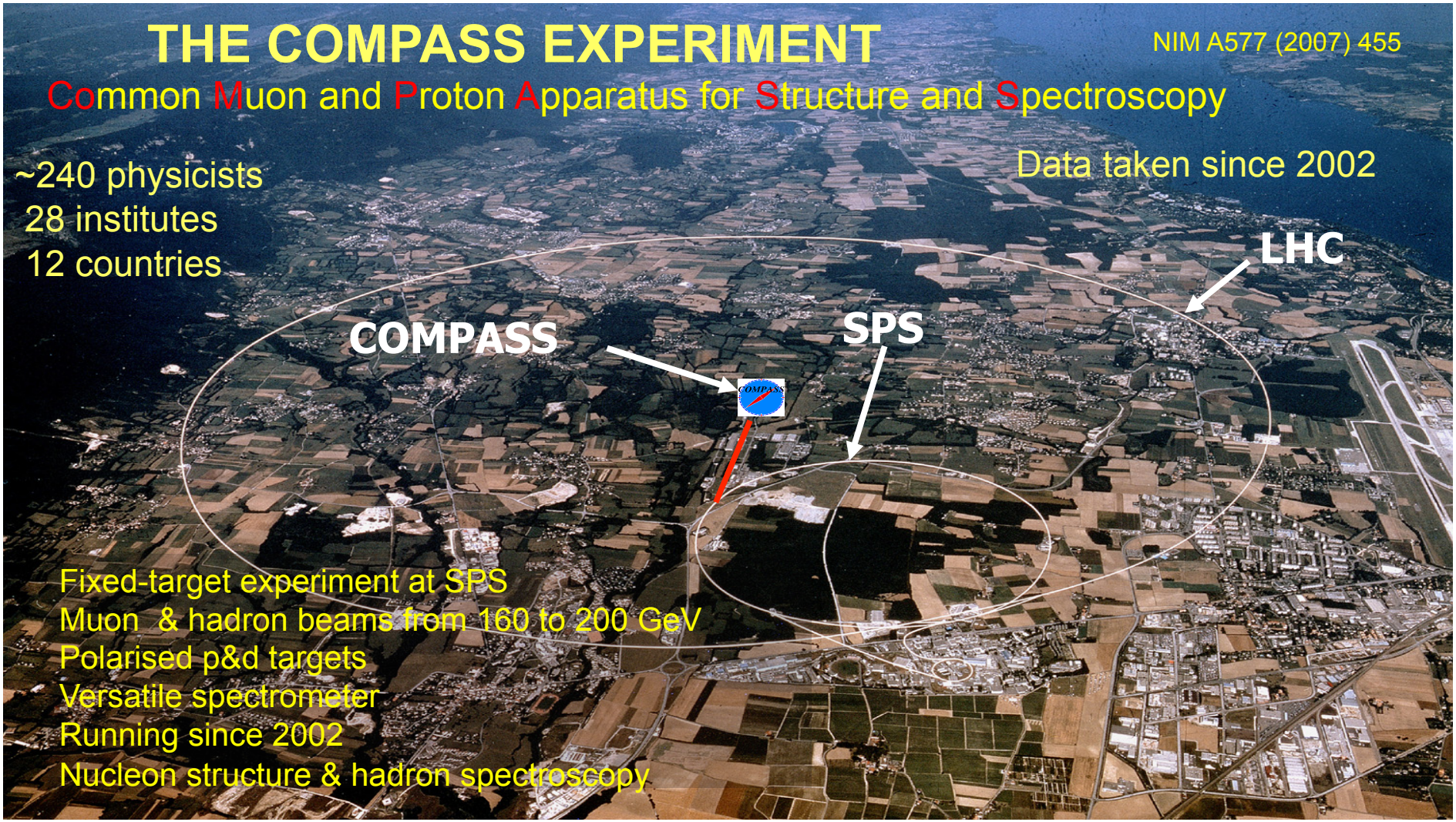
3 Cell Target



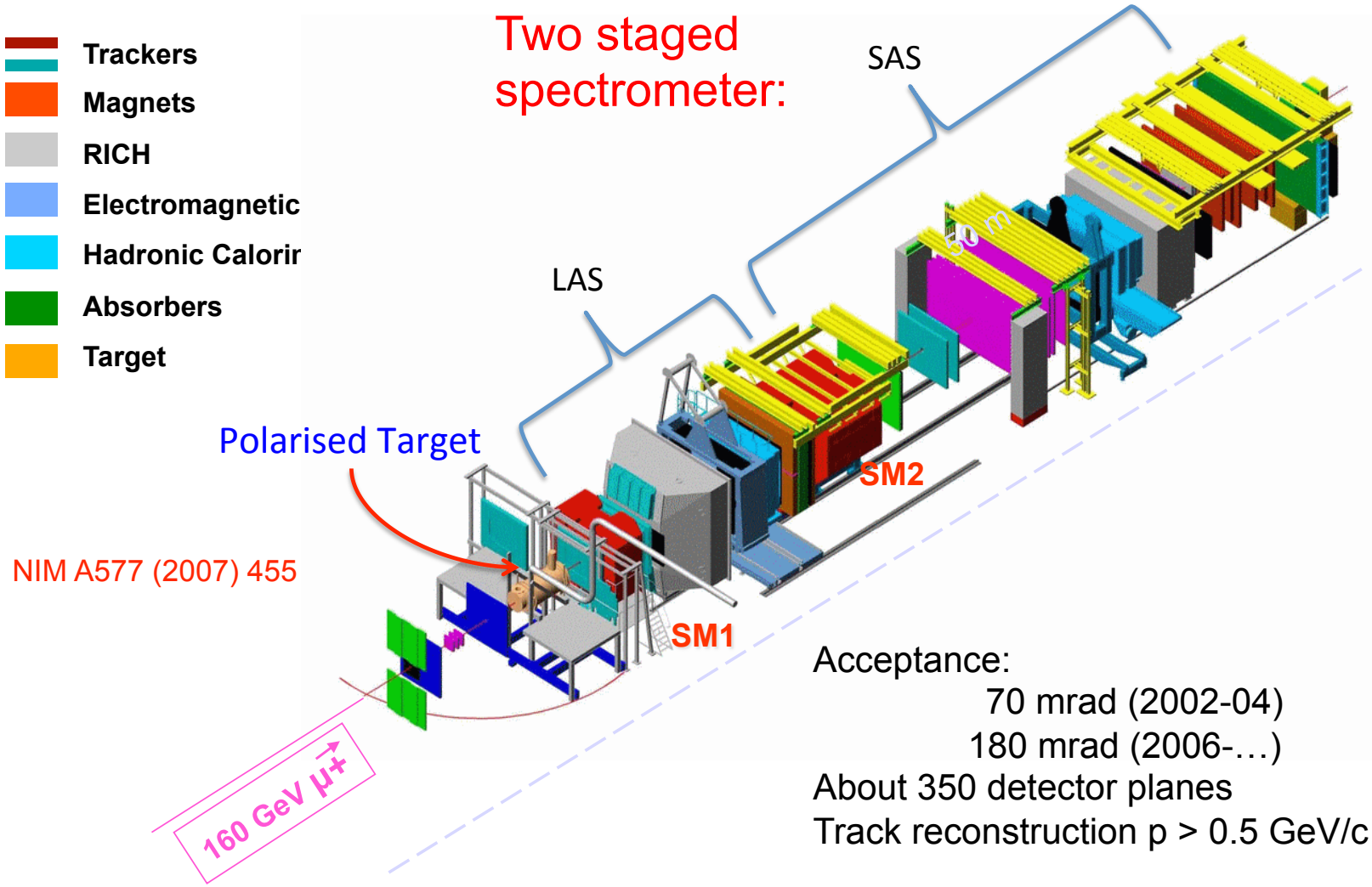
Experimental asymmetry

$$A_{exp} = \frac{1}{2}\left(\frac{N^{\Uparrow} - N^{\Downarrow}}{N^{\Uparrow} + N^{\Downarrow}} + \frac{N^{\Uparrow} - N^{\Downarrow}}{N^{\Uparrow} + N^{\Downarrow}}\right)$$, cancel systematics due to acceptance

COMPASS Experiment @ CERN



Common Muon and Proton Apparatus for Structure and Spectroscopy



NIM A577 (2007) 455

Acceptance:
70 mrad (2002-04)
180 mrad (2006-…)
About 350 detector planes
Track reconstruction p > 0.5 GeV/c

Data Selection

DIS event selection

- $Q^2 > 1(\mathrm{GeV}/c)^2$
- $3 \times 10^{-3} < x_{Bj} < 0.7$
- $0.1 < y < 0.9$
- $W > 5\ \mathrm{GeV}/c^2$

Hadron selection

- $z1, z2 > 0.1$
- $z1 + z2 < 0.9$
- $p_{T1} > 0.7\ \mathrm{GeV}/c$ and $p_{T2} > 0.4\ \mathrm{GeV}/c$

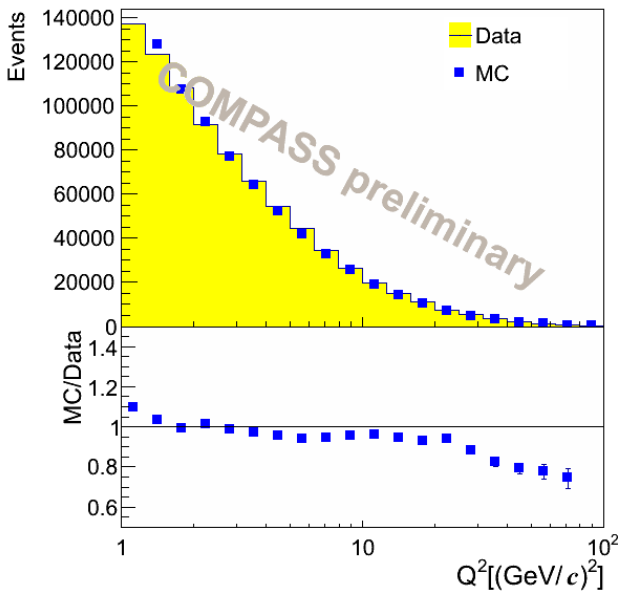
$\Rightarrow$ This set of cuts enhances the correlation between the gluon and the two-hadron azimuthal angles and the fraction of PGF in the sample.

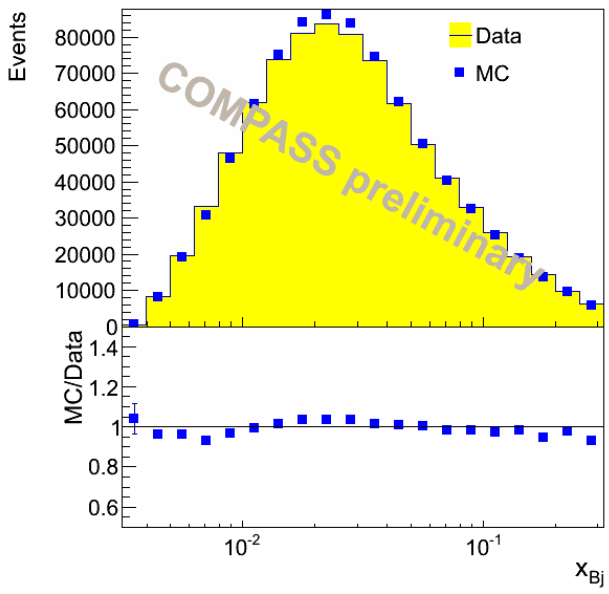
The MC Full Chain

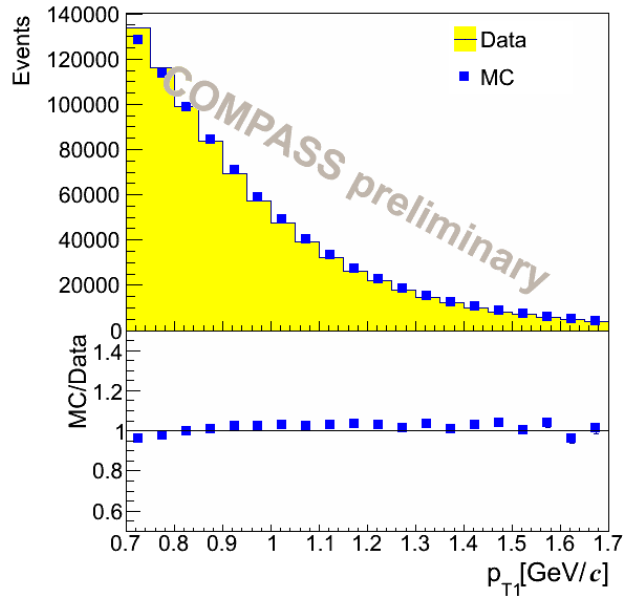
- Generator LEPTO + Apparatus Simulation GEANT + Reconstruction Program.
- PDF: MSTW2008
- Parton Shower: on
- FLUKA for secondary interactions.
- Special generator tuning for high-p_T events, which improves the hadron description.

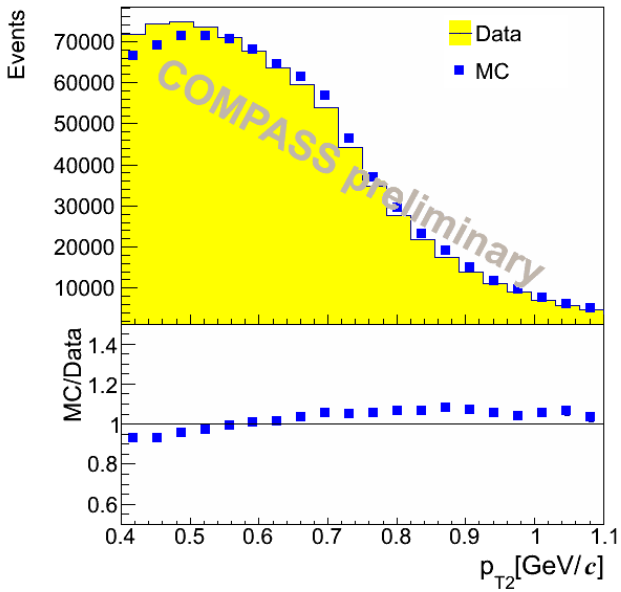
With the full chain MC it was verified that the azimuthal angle of high-p$_T$ pair, ϕ_{2h}, is strongly correlated with the gluon azimuthal angle, ϕ_g.

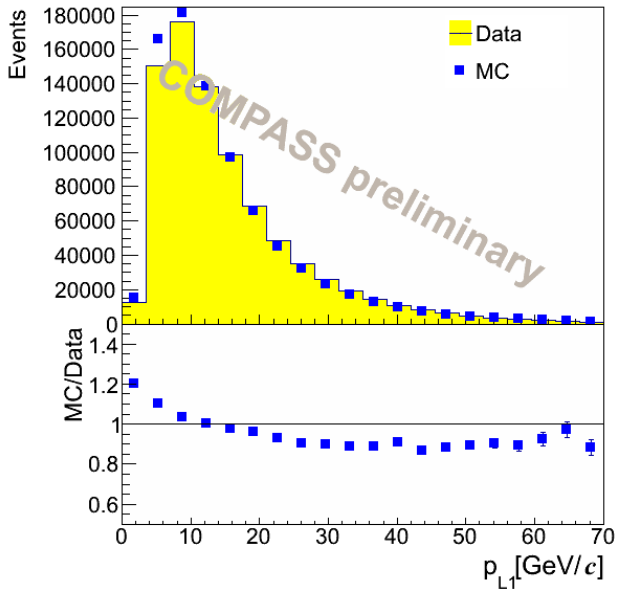
Data MC comparison proton

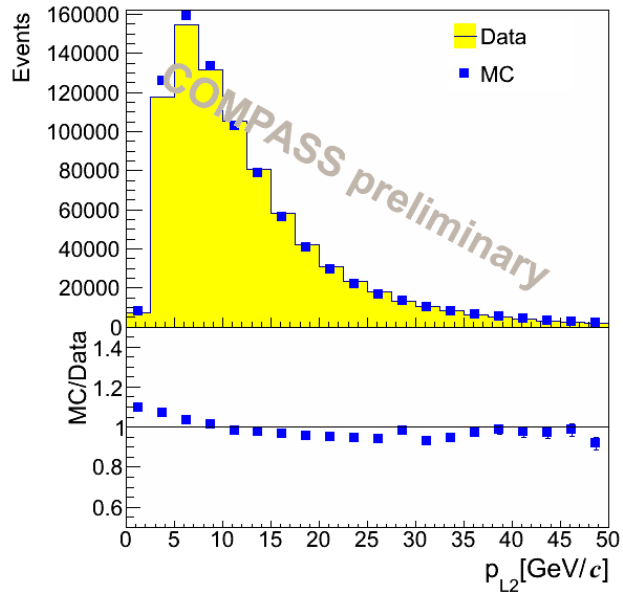




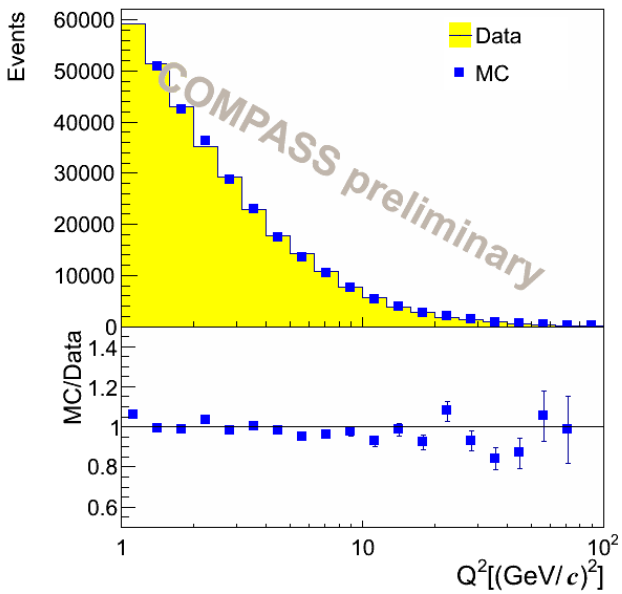


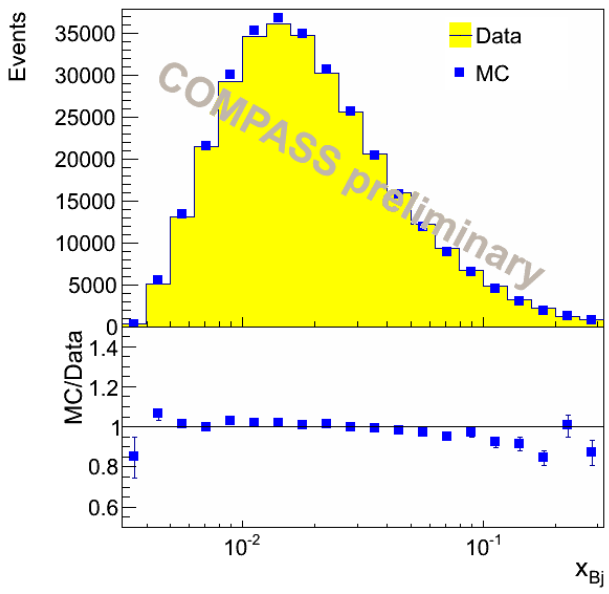


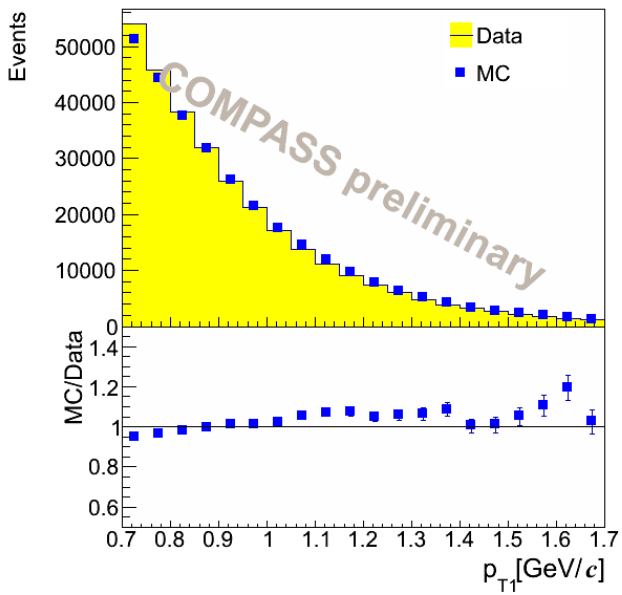


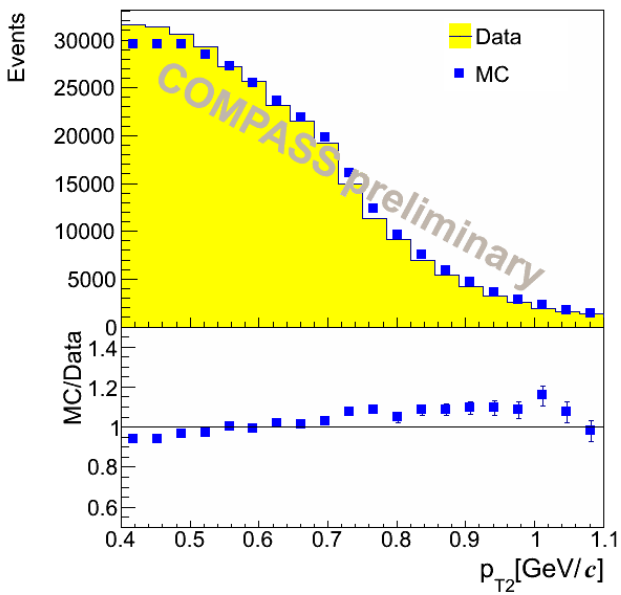


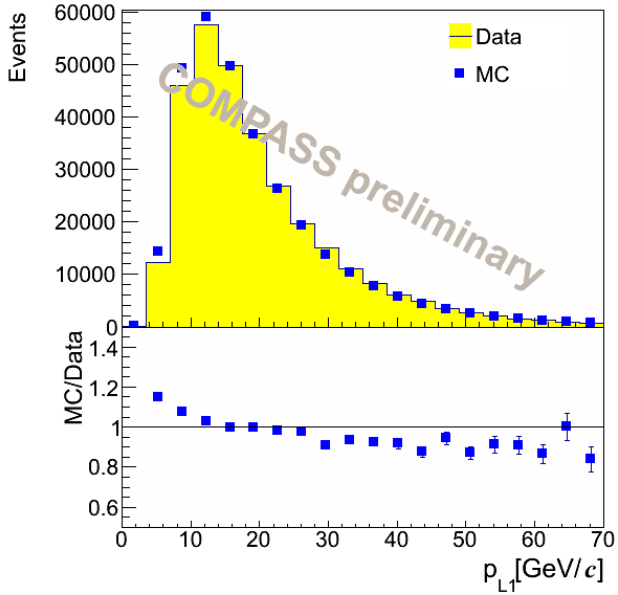
Data MC comparison deuteron

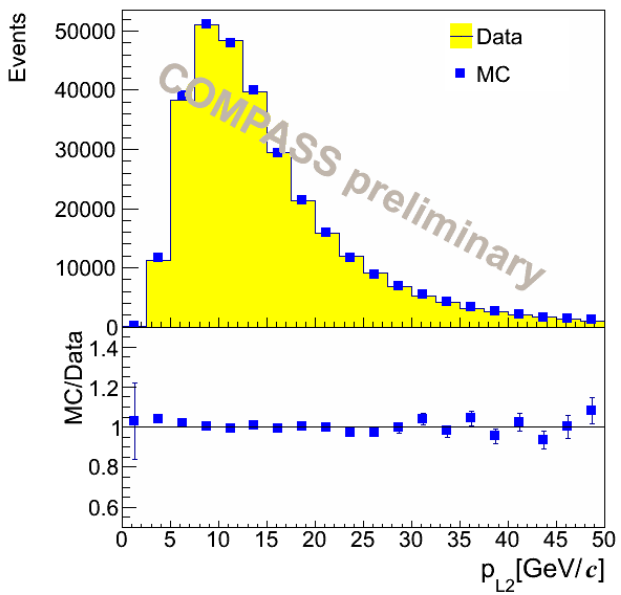












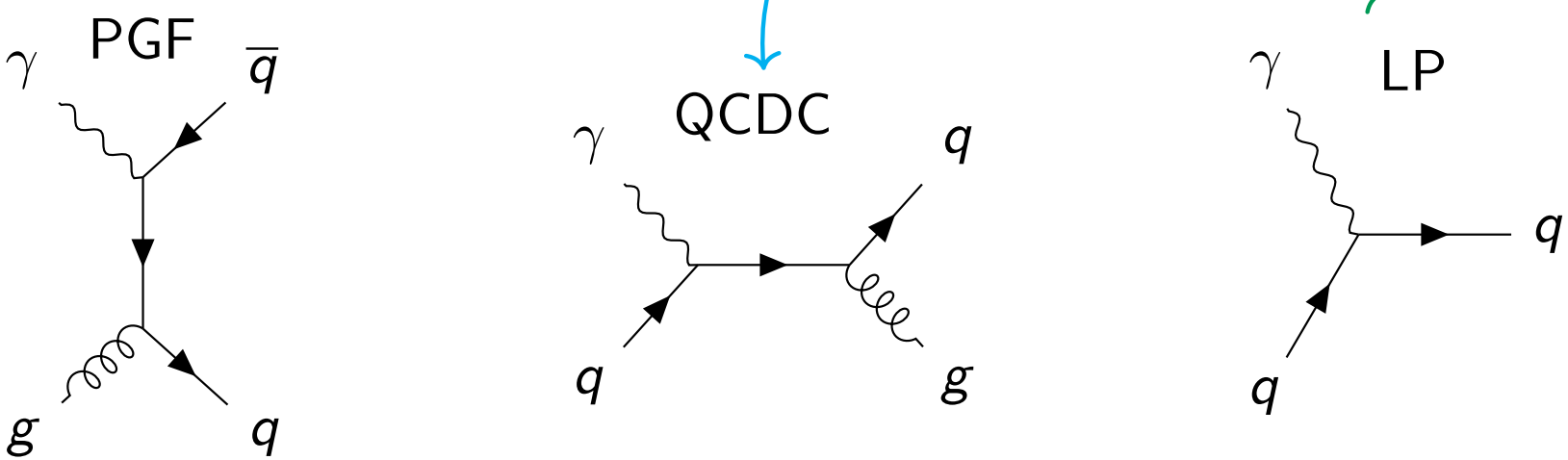
Asymmetries

The Sivers asymmetry can be decomposed as follows:

$$A_T^{2h}(\phi_{\text{Siv}}) = \frac{\Delta\sigma}{\overline{\sigma}}(\phi_{\text{Siv}})$$

$$= \frac{\overline{\sigma}_{\text{PGF}}}{\overline{\sigma}}(\phi_{\text{Siv}})\frac{\Delta\sigma_{\text{PGF}}}{\overline{\sigma}_{\text{PGF}}}(\phi_{\text{Siv}}) + \frac{\overline{\sigma}_{\text{QCDC}}}{\overline{\sigma}}(\phi_{\text{Siv}})\frac{\Delta\sigma_{\text{QCDC}}}{\overline{\sigma}_{\text{QCDC}}}(\phi_{\text{Siv}}) + \frac{\overline{\sigma}_{\text{LP}}}{\overline{\sigma}}(\phi_{\text{Siv}})\frac{\Delta\sigma_{\text{LP}}}{\overline{\sigma}_{\text{LP}}}(\phi_{\text{Siv}})$$

$$= R_{\text{PGF}}(\phi_{\text{Siv}})A_{\text{PGF}}^{2h}(\phi_{\text{Siv}}) + R_{\text{QCDC}}(\phi_{\text{Siv}})A_{\text{QCDC}}^{2h}(\phi_{\text{Siv}}) + R_{\text{LP}}(\phi_{\text{Siv}})A_{\text{LP}}^{2h}(\phi_{\text{Siv}})$$



$\Rightarrow$ LEPTO with LP, QCDC and PGF process describes rather well our data.

Weighting Method

The Number of events in a ϕ_{2h} bin is given by

$$N(\vec{x}, \phi_{\text{Siv}}) = \alpha(\vec{x}, \phi_{\text{Siv}})(1 + f\, P_T\, A^{\text{Siv}} \sin\phi_{\text{Siv}}),$$

$$\alpha^t = a^t \Phi n^t \sigma_o \quad , \quad \beta_i^t = R_i\, f\, P_T^t \sin\phi_{\text{Siv}},$$

$$N^t = \alpha^t \left(1 + \beta^t_{PGF}\, A^{\text{Siv}}_{PGF} + \beta^t_{QCDC}\, A^{\text{Siv}}_{QCDC} + \beta^t_{LP}\, A^{\text{Siv}}_{LP}\right)$$

't' runs for all target configurations : 1) $\Uparrow$, 2) $\Downarrow$, 3) $\Downarrow$ and 4) $\Uparrow$
'i' and 'j' run for the process: PGF, QCDC and LP

$$p_j^t := \int \omega_j(\phi_{\text{Siv}}) N^t(\vec{x}) d\vec{x} \quad \approx \sum_{k=1}^{N^t} \omega_j^k$$

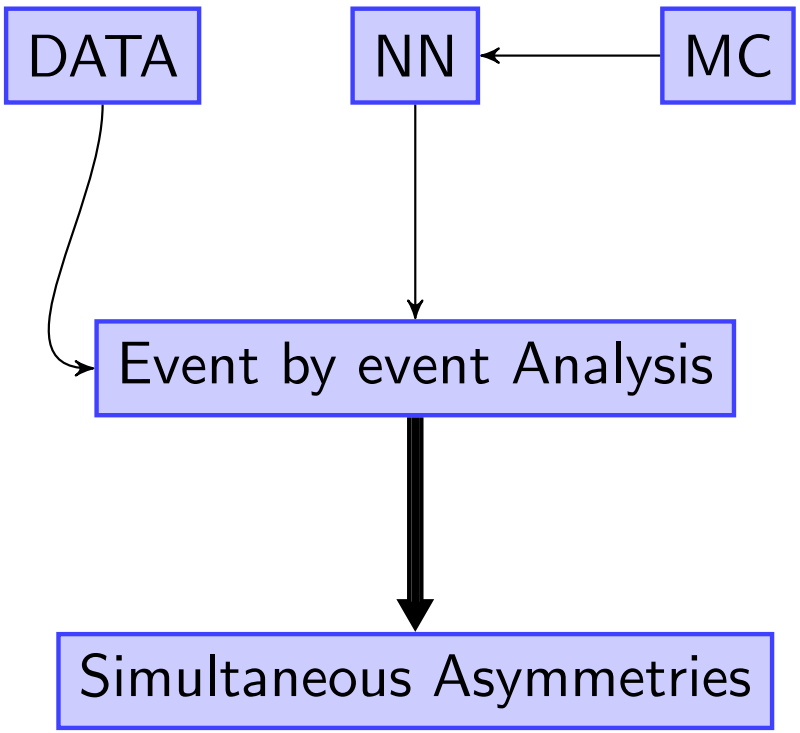
$$= \tilde{\alpha}_j^t \left(1 + \{\beta^t_{PGF}\}_{\omega_j} A^{\sin\phi_{\text{Siv}}}_{PGF} + \{\beta^t_{QCDC}\}_{\omega_j} A^{\sin\phi_{\text{Siv}}}_{QCDC} + \{\beta^t_{LP}\}_{\omega_j} A^{\sin\phi_{\text{Siv}}}_{LP}\right),$$

$$\frac{\tilde{\alpha}_j^1 \tilde{\alpha}_j^4}{\tilde{\alpha}_j^3 \tilde{\alpha}_j^2} = 1 \Rightarrow \text{limits the number of unknowns.}$$

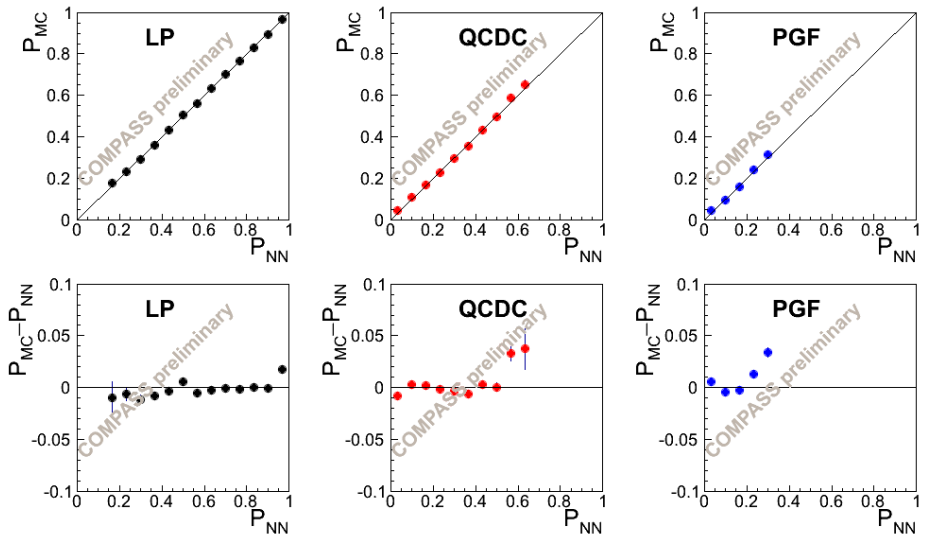
$$\omega_j = R_j f \sin\phi_{\text{Siv}} = \beta_j / P_T \quad , \quad \{\beta_i^t\}_{\omega_j} = \frac{\int \alpha^t \beta_i^t \omega_j d\vec{x}}{\int \alpha^t \omega_j d\vec{x}} \approx \frac{\sum_k^{N^t} \beta_k^t \omega_j}{\sum_k^{N^t} \omega_j^k}$$

At the end, a set of equations is solved by χ^2 minimisation.

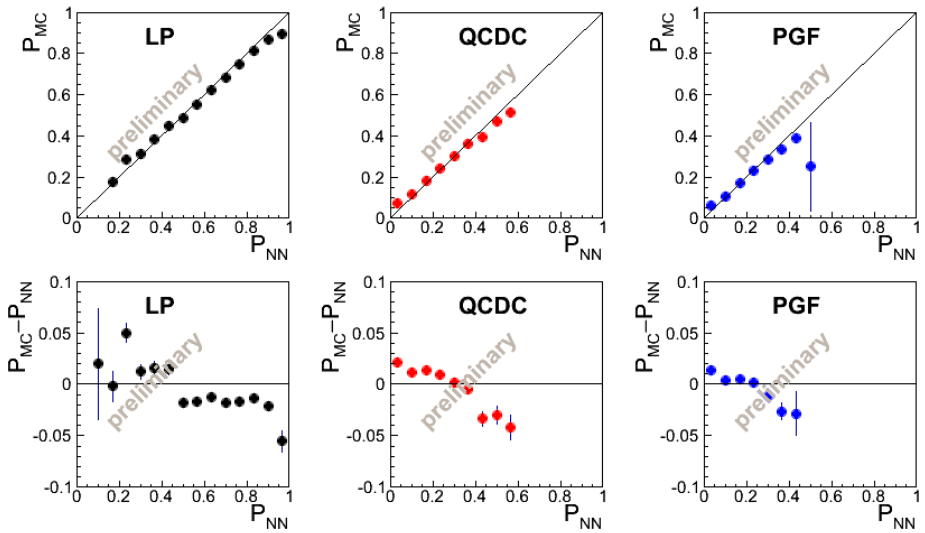
Neural Network Approach



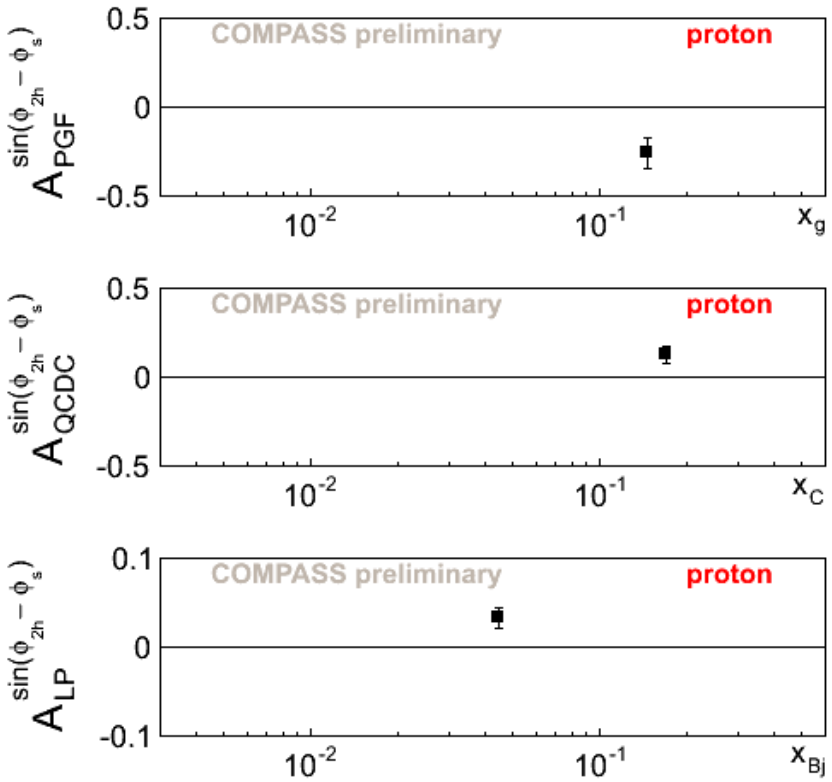
Proton:

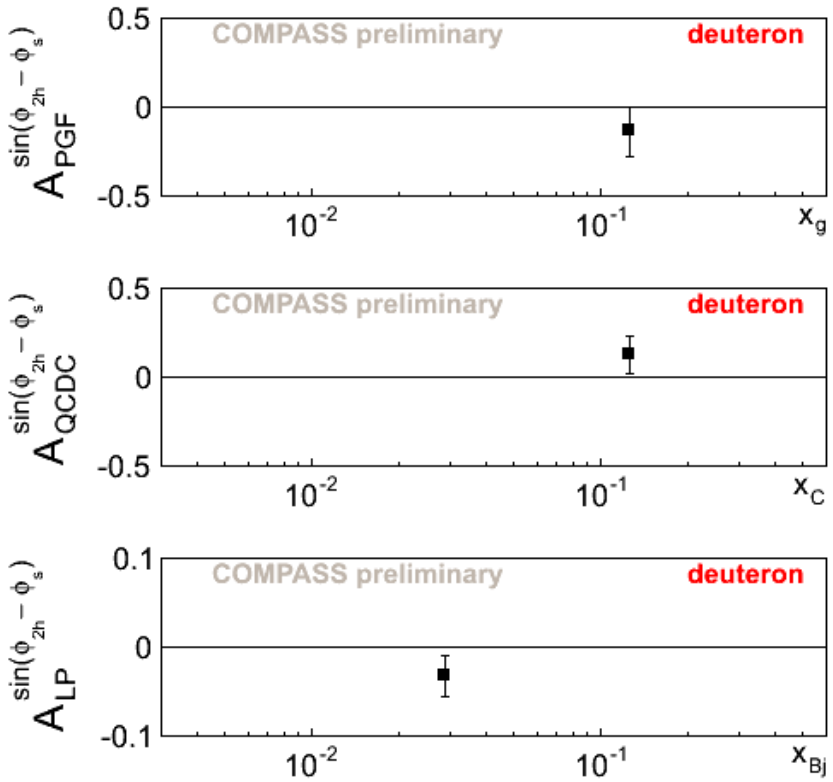


Deuteron:



Results: Sivers





proton

$$A_{\mathrm{PGF}}^{\sin(\phi_{2h}-\phi_S)} = -0.26 \pm 0.09(\mathrm{stat.})$$

$$@\ \langle x_g \rangle = 0.15$$

deuteron

$$A_{\mathrm{PGF}}^{\sin(\phi_{2h}-\phi_S)} = -0.14 \pm 0.15(\mathrm{stat.})$$

$$@\ \langle x_g \rangle = 0.13$$

Systematic uncertainties are smaller than statistical ones.

Summary and Outlook

Summary

- To enhance contribution of the PGF process and enhance the correlation of the gluon azimuthal angle with physical observables high-p_T hadron pair events were selected from proton and deuteron data.
- A dedicated full MC chain was generated and used for NN analysis.
- The separation between PGF and LP and QCDC contributions was reinforced using a NN approach. All three contributions were simultaneously extracted.
- For the first time, COMPASS extracted the gluon Sivers asymmetry using DIS electroproduction of high-p_T hadron pair off transversely polarised proton and deuteron targets.
- The combined gluon Sivers asymmetry using proton and deuteron data is -0.22, more than 2σ from 0.

Outlook

A paper is been prepared to be submitted to PLB

BACKUP SLIDES