Gluon-induced Sivers-like asymmetries at COMPASS

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On behalf of the COMPASS Collaboration

30. 9. 2020, JINR remote workshop
Gluon content of proton and deuteron
with the Spin Physics Detector at the NICA collider

Outline

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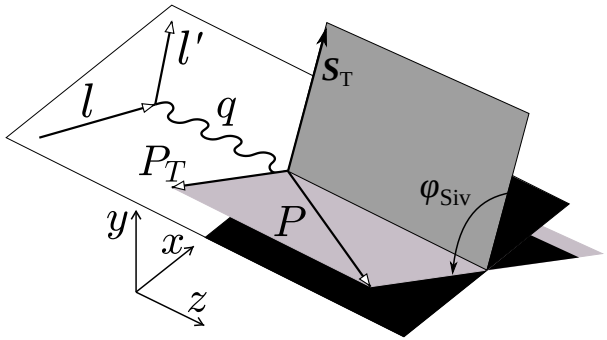
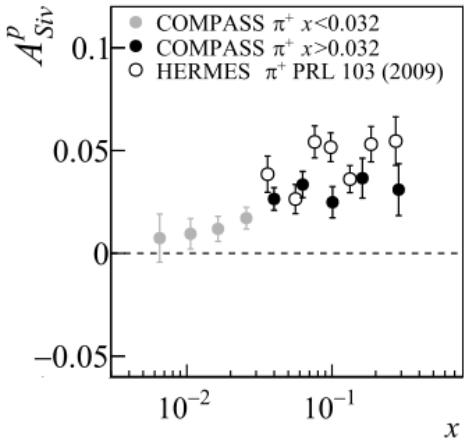
Introduction: Gluonic Sivers function

Sivers function $f_{1T}^{\perp}$: correlation of the partonic transverse momentum $\boldsymbol{k_T}$ and of the nucleon transverse spin.



Sivers angle in SIDIS.



Sivers effect measured on π^+.
[COMPASS, Phys.Lett.B744 (2015)]

- Nonzero $f_{1T}^{\perp u}$ explains the observed left–right asymmetry in $\ell p^{\uparrow} \to \ell' h^+ X$.
- It can be linked to the intrinsic orbital angular momentum.
- Restricted universality: $f_{1T}^{\perp q[\mathrm{SIDIS}]} = -f_{1T}^{\perp q[\mathrm{DY}]}$
- Sivers function of gluons is practically unknown.
- Restricted universality: Combinations of two universal functions in different processes:
  [Buffing *et al.*, Phys.Rev.D88 (2013)], [D. Boer's talk today] [C. Pisano's talk today]

  f-type (or $[+,+]$, $[-,-]$ types): $\gamma^\star g \to Q\bar{Q}$, $gg \to \gamma\gamma$, $gg \to Q\bar{Q}$.
  d-type (or $[+,-]$, $[-,+]$ types): $qg \to \gamma q$

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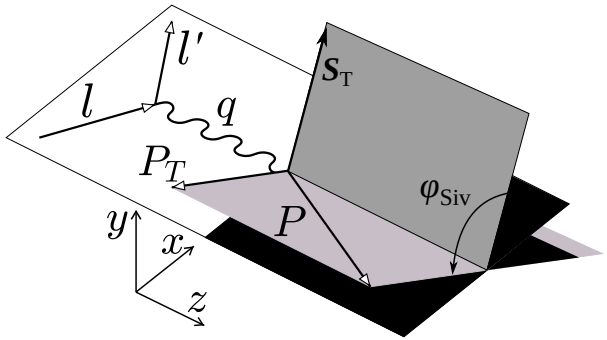

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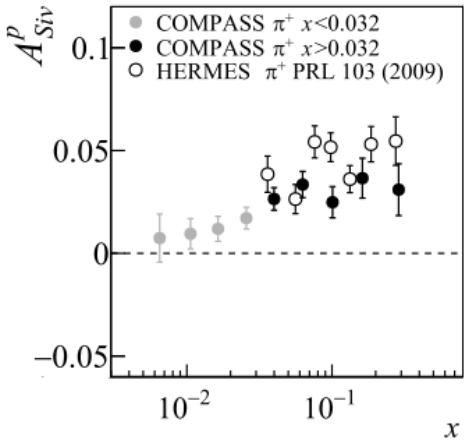

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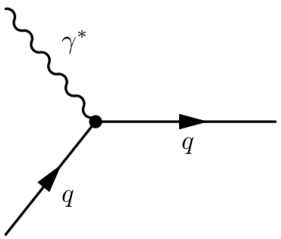
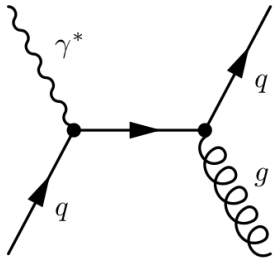
Introduction: Access to gluons in muon–nucleon scattering

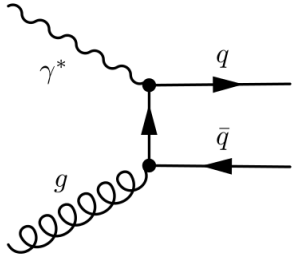
Single-γ exchange processes describing well the μ–nucleon scattering:



Leading process (LP).



QCD Compton process (QCDC).



Photon-gluon fusion (PGF).

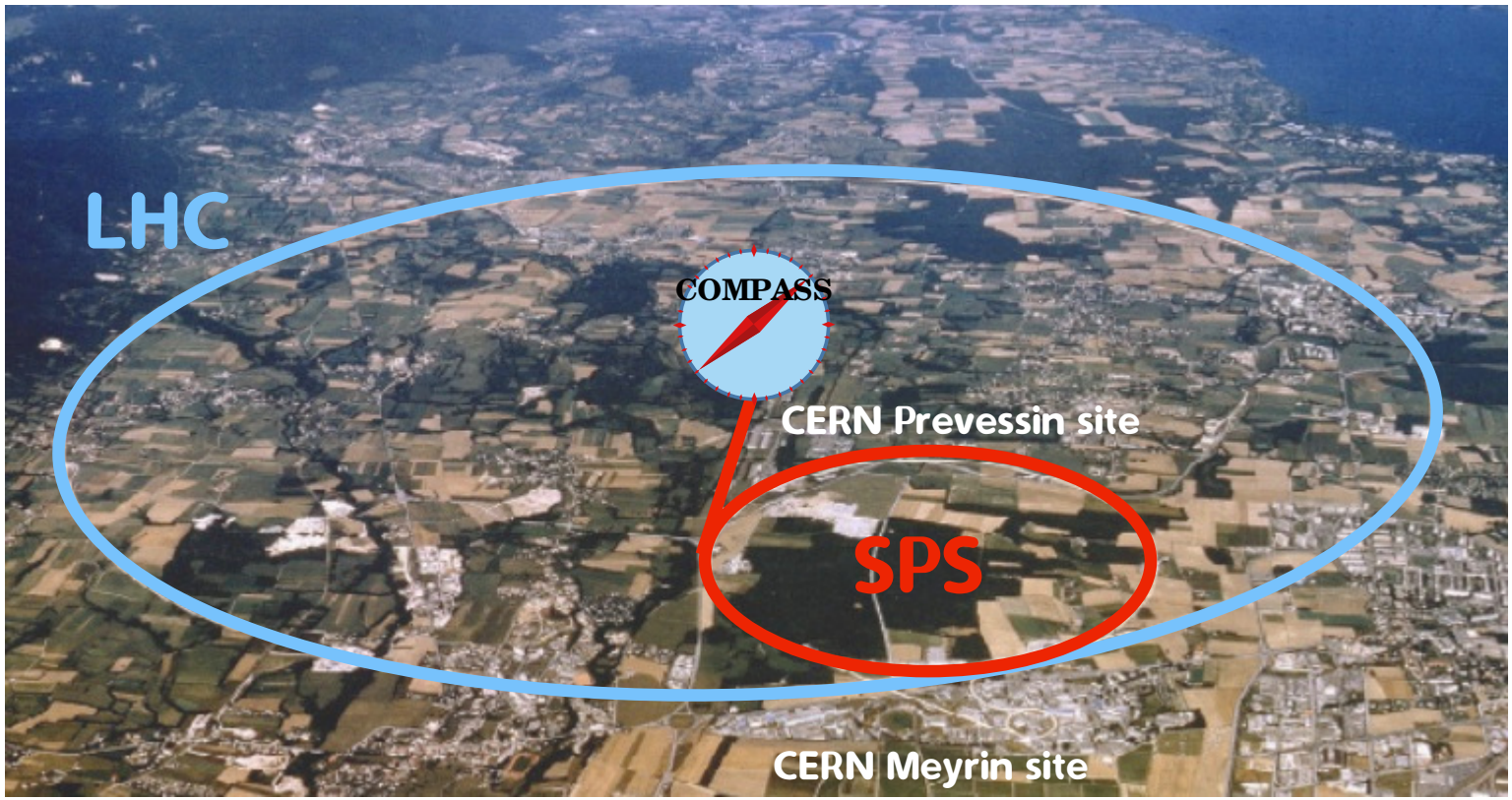
PGF gives access to gluons. How to tag it?

- $q\bar{q}$ are heavy flavour ($c\bar{c}$ on COMPASS E)
  - "open charm": D mesons in the final state,
  - J/ψ in the final state.
- $q\bar{q}$ have large transverse momentum p_T,
  - LP: p_T only from intrinsic quark k_T and fragmentation.
  - QCDC, PGF: p_T naturally present (higher order).

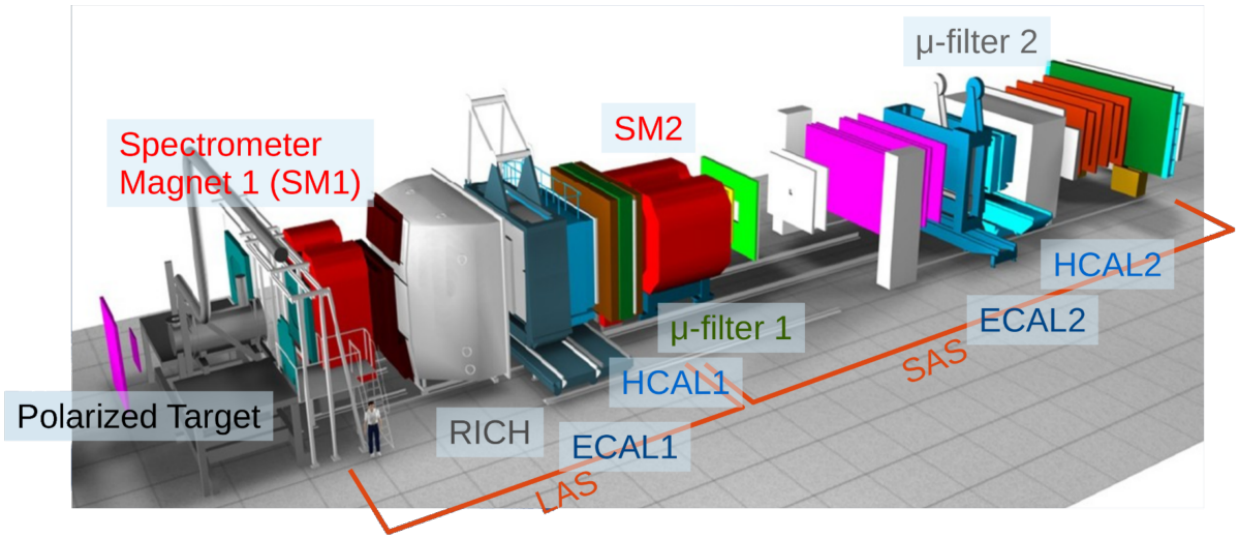
Using these methods, $f_{1T}^{\perp g}$ can be studied in SIDIS with transversely-polarised target.

Introduction: COMPASS

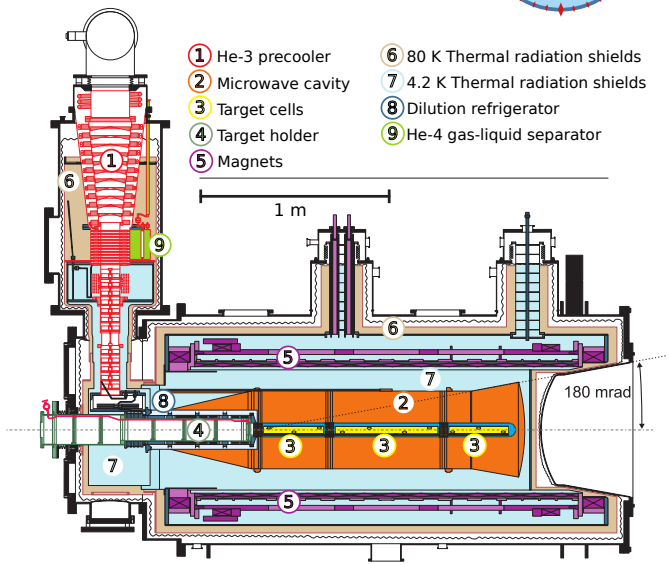
- COMPASS Collaboration: 24 institutions from 13 countries ($\approx$ 220 physicists).
- Experimental area: CERN Super Proton Synchrotron (SPS) North Area.
- Two-stage spectrometer, about 350 detector planes, μ identification.
- Multi-purpose apparatus with rich physics program since 2002
  aimed at hadron structure and spectroscopy.



Introduction: Transversely polarised SIDIS programme



Setup for SIDIS with 160 GeV/c μ^+ beam.



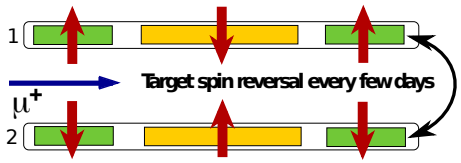
Polarised target (new magnet).

2002–2004

- Polarised ^{6}LiD target.
- $f = 0.4$, $P_{\text{targ.}} = 0.5$
- Old target magnet (70 mrad).

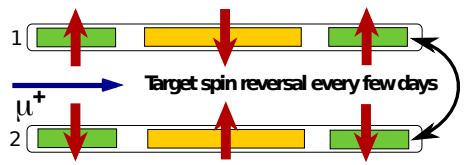
2007, 2010

- Polarised NH_3 target.
- $f = 0.16$, $P_{\text{targ.}} = 0.9$
- New target magnet (180 mrad).



2021 (in preparation)

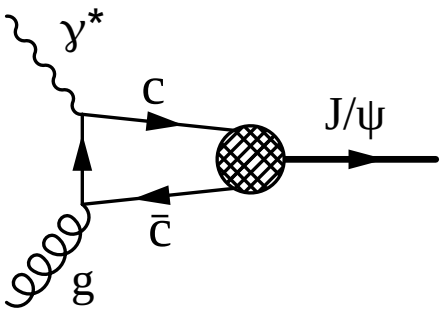
- Polarised ^{6}LiD target.
- $f = 0.4$, $P_{\text{targ.}} = 0.5$
- New target magnet (180 mrad).



- Acceptance in polarisation-dependent azimuthal angles is cancelled.

Outline

J/ψ leptoproduction: Theoretical motivation

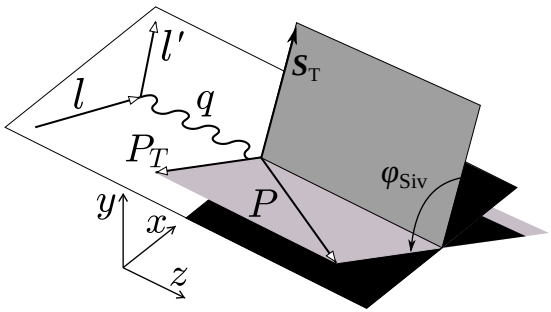


J/ψ formed in PGF.

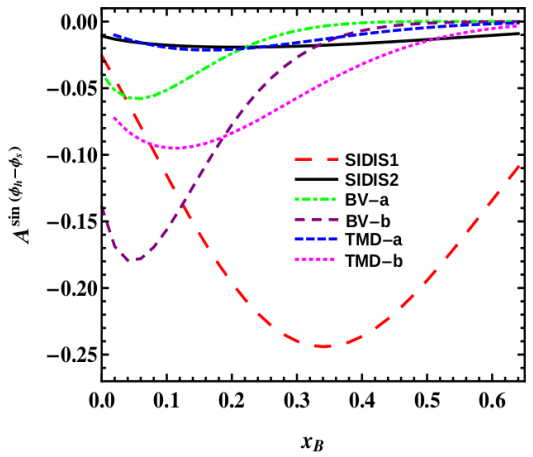
- Color octet model: $c\bar{c}$ in colour octet state → J/ψ via soft gluon radiation.
- Transition probabilities between them given by NRQCD.
- Azimuthal distribution of g preserved, $\phi_g = \phi_{J/\psi}$,
- → Sivers-like modulation in $\phi_{Siv} = \phi_{J/\psi} - \phi_S$

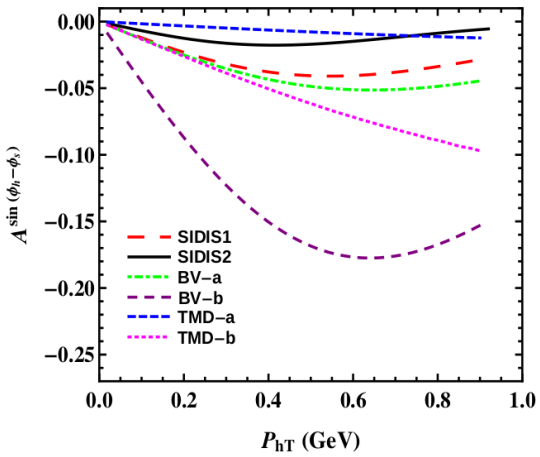
$$\sigma(\phi_{Siv}) = \sigma_0\left(1 + f P_{tar.} A^{p}_{Siv} \sin(\phi_{Siv})\right)$$

- [Mukherjee and Rajesh, Eur.Phys.J.C77 (2017)], [Bacchetta *et al.*, Eur.Phys.J.C 80 (2020)].



The Sivers angle (here $P = P_{J/\psi}$).

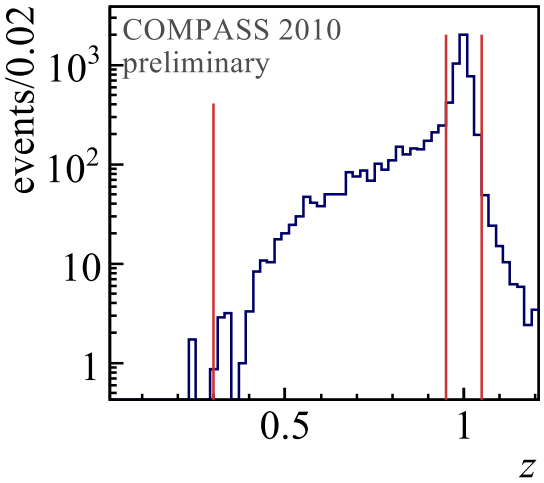




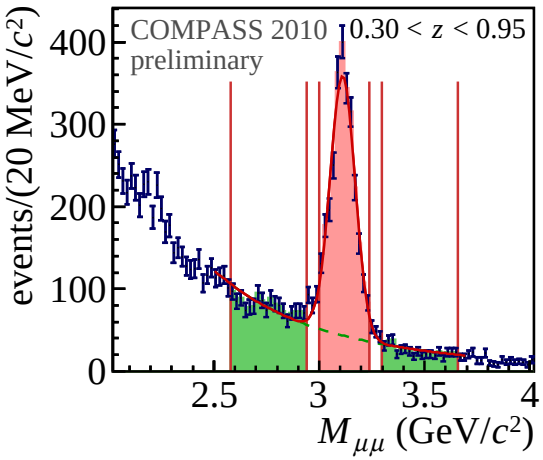
Projections for COMPASS energy, [Mukherjee and Rajesh, Eur.Phys.J.C77 (2017)].

J/ψ leptoproduction: Data analysis

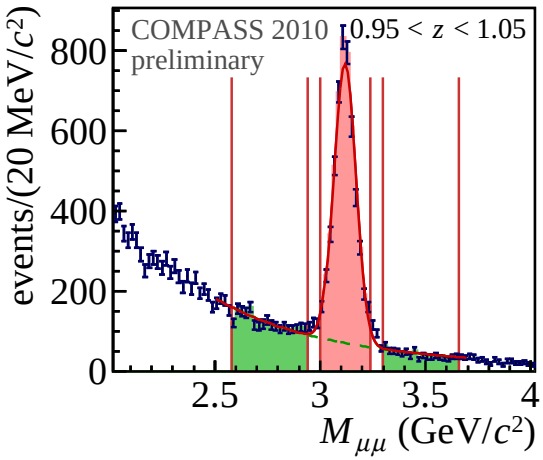
- $\mu^+ p^\uparrow \to \mu^+ J/\psi\, X \to \mu^+\mu^+\mu^- X$.
- Both possible combinations of $\mu^+\mu^-$ used.
- 2010 proton data.
- No Q^2 cut imposed (hard scale = $c\bar{c}$ mass).
- Two bins z: inclusive, exclusive.
- Clear J/ψ signal (3.1 GeV/c^2, $\sigma \approx 55$ MeV/c^2).
- Small background, limited statistics ($\approx$ 2300 incl., 4500 excl.).



Energy fraction transferred to J/ψ.

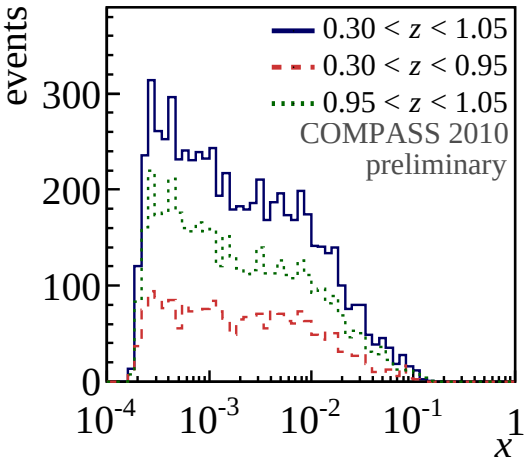


Invariant mass, inclusive bin.

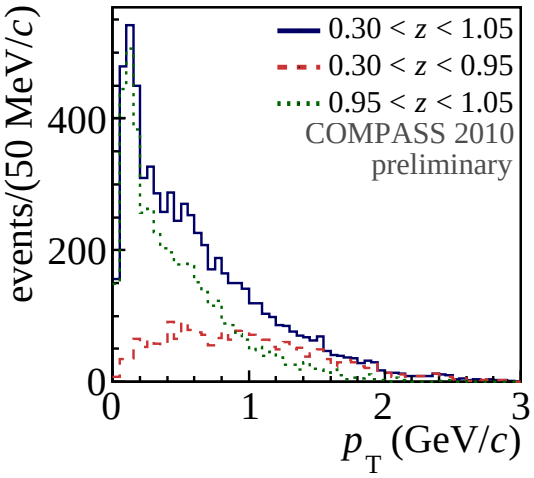


Invariant mass, exclusive bin.

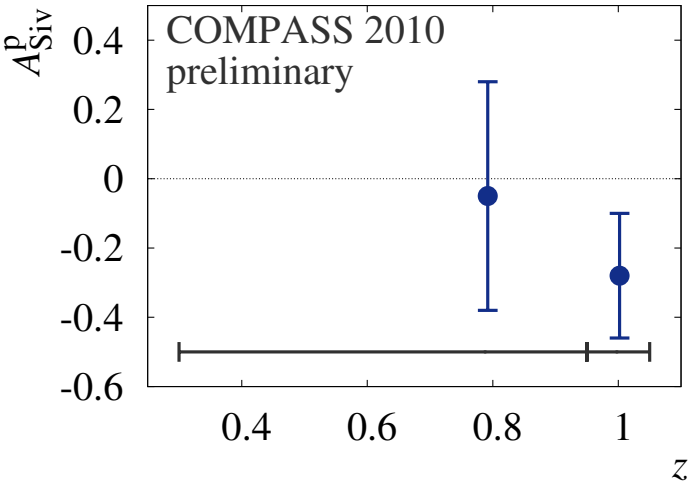
J/ψ leptoproduction: Results



The $x_{\mathrm{Bj.}}$ distribution.



The P_{T} distribution.



The measured Sivers-like asymmetry.

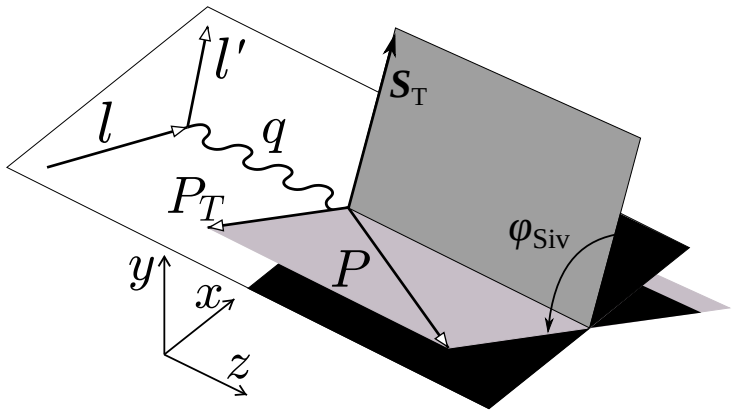
- $A^{\mathrm{p}}_{\mathrm{Siv}} = -0.28 \pm 0.18$ (**preliminary**, exclusive J/ψ).
- Prospects for improving statistics:
  - Old ^{6}LiD data: small effect,
  - Planned 2021 ^{6}LiD data: $\approx$ factor of 2.
- We are considering analysing other J/ψ asymmetries and a paper.

Outline

High p_{T} hadrons: Event selection

- $\mu^+ N^\uparrow \to \mu^+ h_1 h_2 X$.
- 2003–2004 deuteron data, 2010 proton data.
- DIS cuts: $Q^2 > 1\ (\mathrm{GeV}/c)^2$, $W > 5\ \mathrm{GeV}/c^2$, $0.003 < x_{\mathrm{Bj.}} < 0.7$ and $0.1 < y < 0.9$
- The correlation of ϕ_{g} to various observables studied in LEPTO MC.
- $h_{1,2}$: charged hadrons with the largest and second-largest p_{T}.
- Hadron cuts: $p_{\mathrm{T}1} > 0.7\ \mathrm{GeV}/c$, $p_{\mathrm{T}2} > 0.3\ \mathrm{GeV}/c$, $z_i > 0.1$ and $z_1 + z_2 < 0.9$.
- The azimuthal angle ϕ_P of $P = p_1 + p_2$ is correlated with ϕ_{g}.
- Gluonic Sivers effect induces a Sivers-like modulation in $\phi_{\mathrm{Siv}} = \phi_P - \phi_S$

$$\sigma_{\mathrm{PGF}}(\phi_{\mathrm{Siv}}) = \sigma_0 \left(1 + f P_{\mathrm{tar.}} A_{\mathrm{PGF}}^{\sin\phi_{\mathrm{Siv}}} \sin\phi_{\mathrm{Siv}}\right).$$



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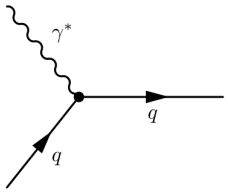
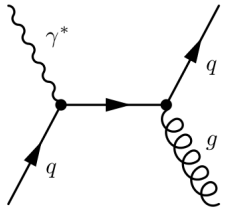
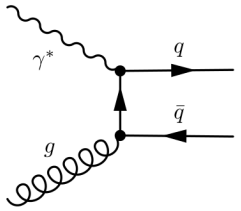


Leading process (LP).



QCD Compton process (QCDC).



Photon-gluon fusion (PGF).

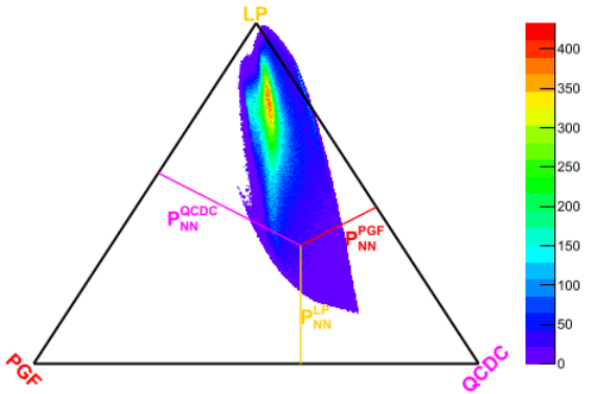
- Mixture of subprocesses: Events in a certain bin given by

$$N(\boldsymbol{x},\phi_{\mathrm{Siv}}) = a(\boldsymbol{x},\phi_{\mathrm{Siv}})\big[1 + \beta_{\mathrm{PGF}}(\boldsymbol{x},\phi_{\mathrm{Siv}})A_{\mathrm{PGF}}^{\sin\phi_{\mathrm{Siv}}}(\boldsymbol{x}) + \beta_{\mathrm{LP}}(\boldsymbol{x},\phi_{\mathrm{Siv}})A_{\mathrm{LP}}^{\sin\phi_{\mathrm{Siv}}}(\boldsymbol{x}) + \beta_{\mathrm{QCDC}}(\boldsymbol{x},\phi_{\mathrm{Siv}})A_{\mathrm{QCDC}}^{\sin\phi_{\mathrm{Siv}}}(\boldsymbol{x})\big]$$

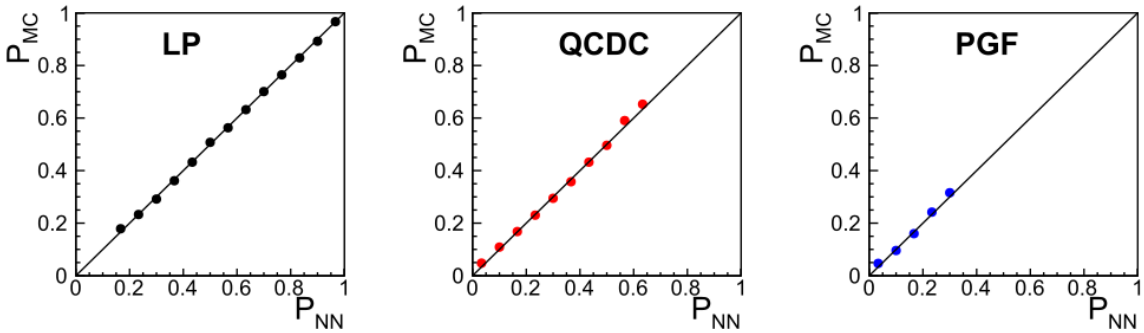
- $\beta_j(\boldsymbol{x},\phi_{\mathrm{Siv}}) = R_j(\boldsymbol{x}) f P_{\mathrm{targ.}} \sin\phi_{\mathrm{Siv}}$, where $j = \mathrm{PGF}, \mathrm{LP}, \mathrm{QCDC}$.
- R_j are the subprocess fractions, obtained from a neural network (NN) trained on MC.
- Assuming R_j are independent of $A_j^{\sin\phi_{\mathrm{Siv}}}$.
- $A_j^{\sin\phi_{\mathrm{Siv}}}$ can be obtained by a simultaneous fit.
- The same method used for $\Delta g/g$ measurement (the talk of Marcin Stolarski, [COMPASS, Phys.Lett.B718 (2013)]).

High p_T hadrons: Monte Carlo

- LEPTO generator (MSTW08 PDFs, parton shower on),
- Geant with COMPASS setup,
- FLUKA for secondary interactions.
- NN trained on 6 variables: $p_{T1}, p_{T2}, p_{L1}, p_{L2}, Q^2, x_{Bj}$.

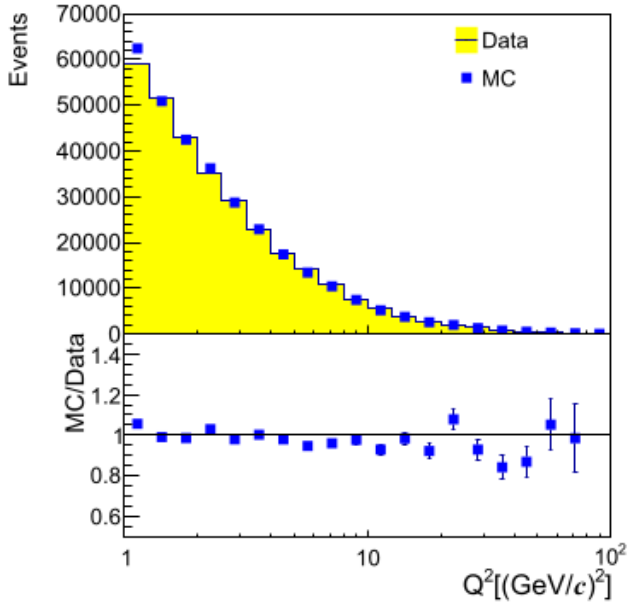


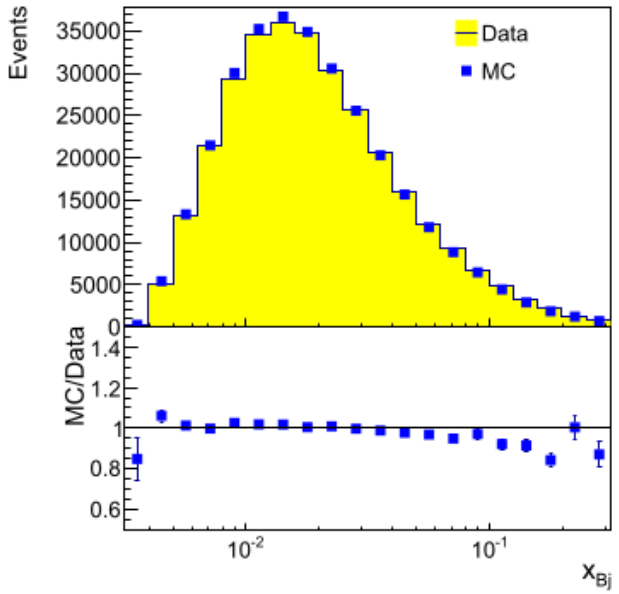
The probabilities assigned to events by the NN after training represented as distances from the triangle sides.

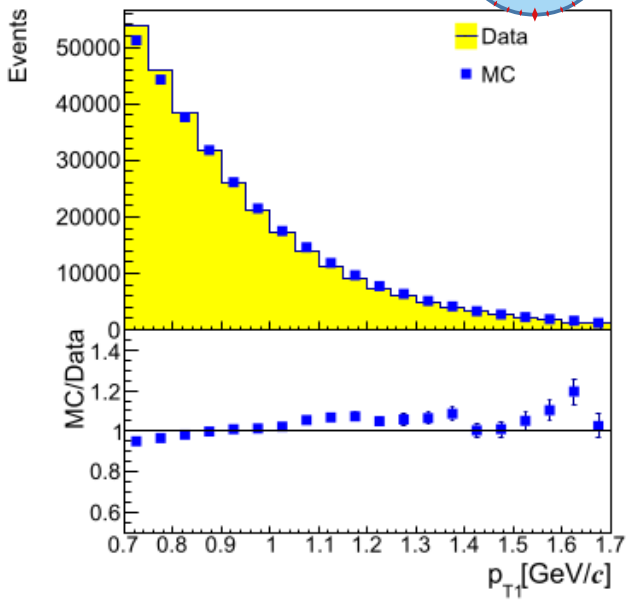


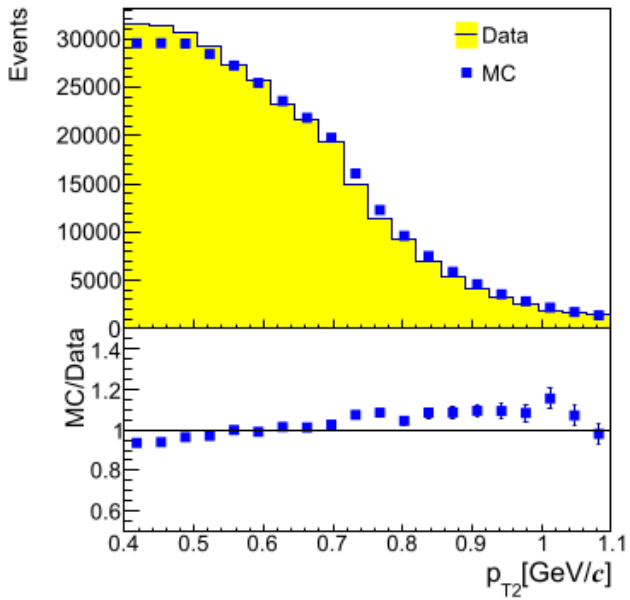
Validation of the NN on an independent MC sample.

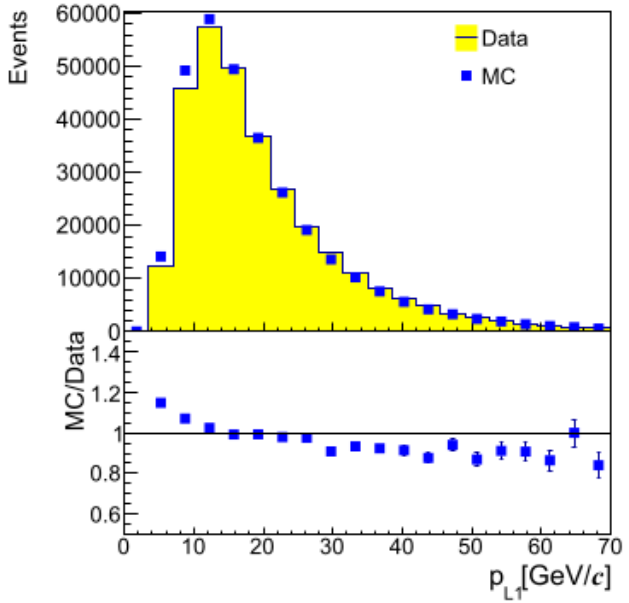
High p_T hadrons: Data–MC comparison for deuteron

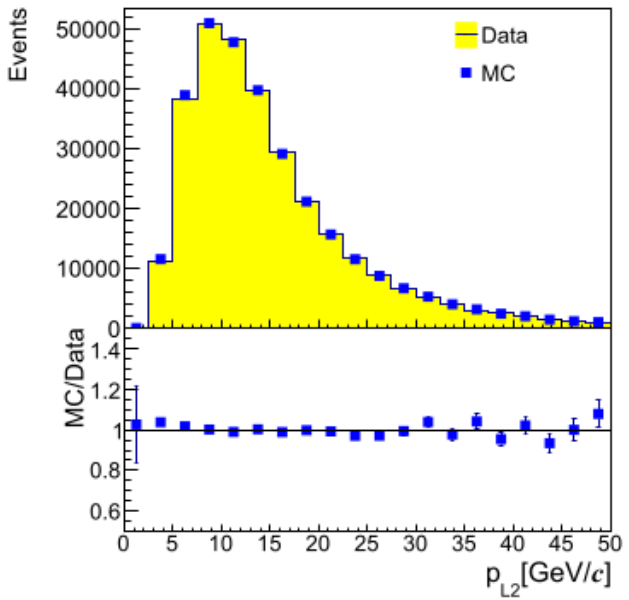




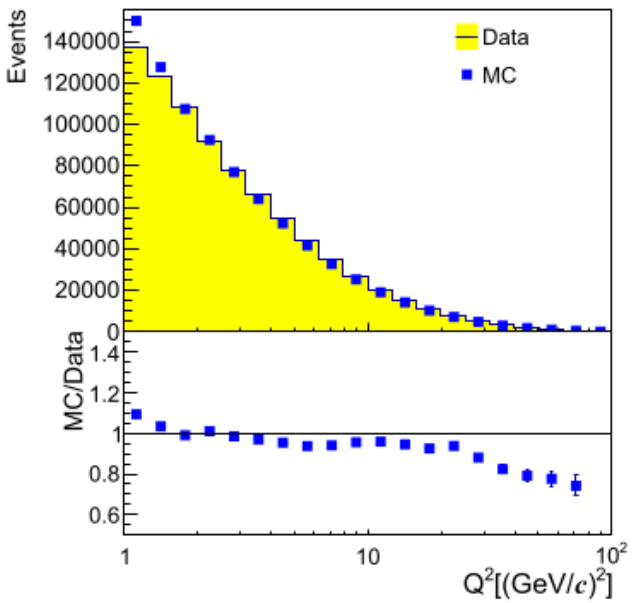


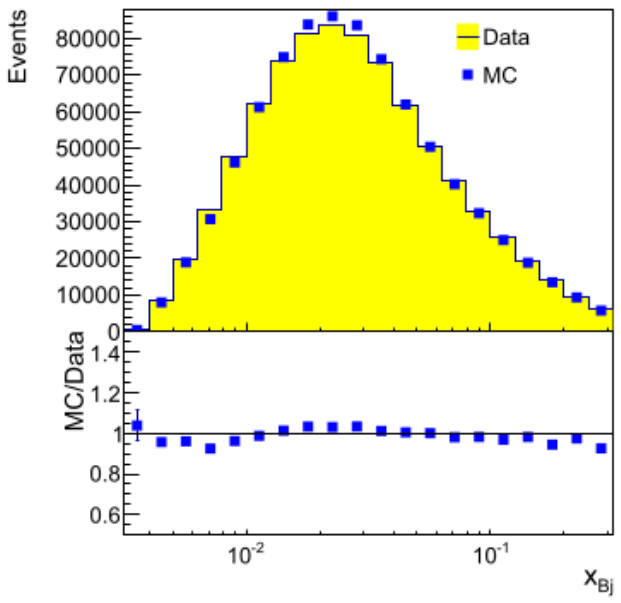


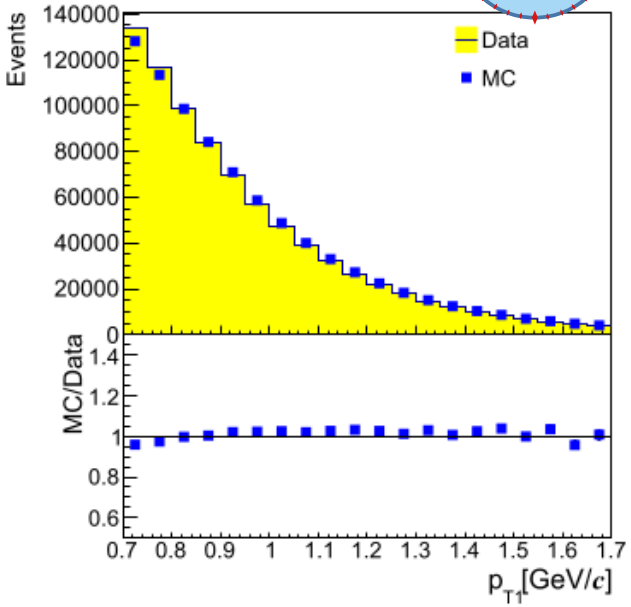


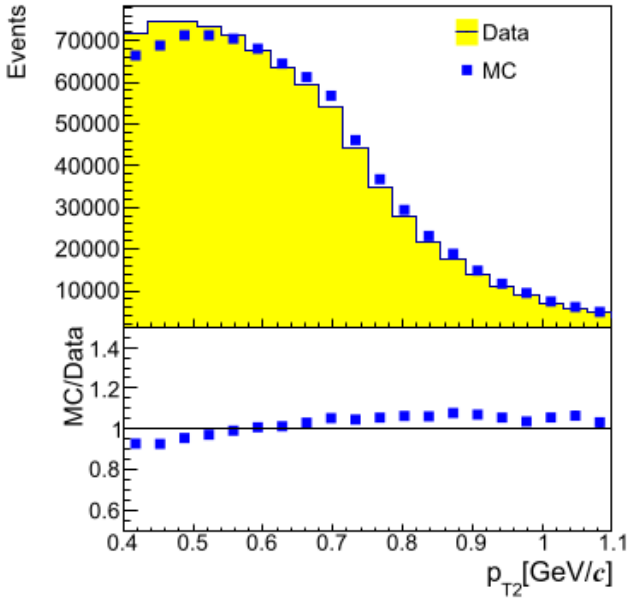


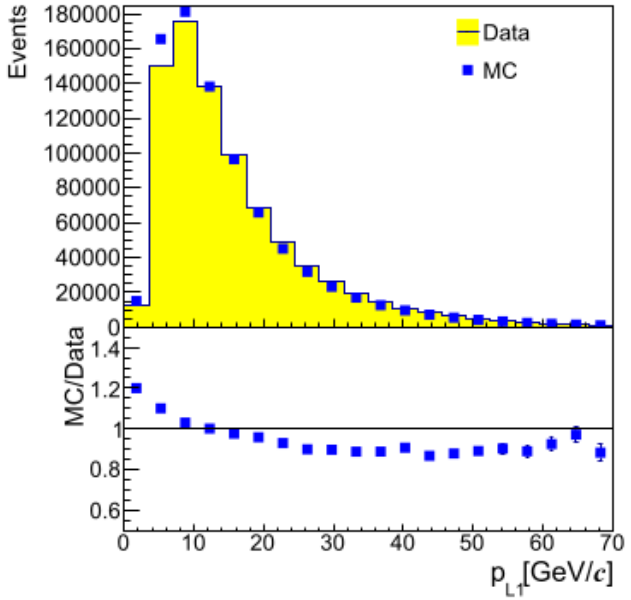
High p_T hadrons: Data–MC comparison for proton

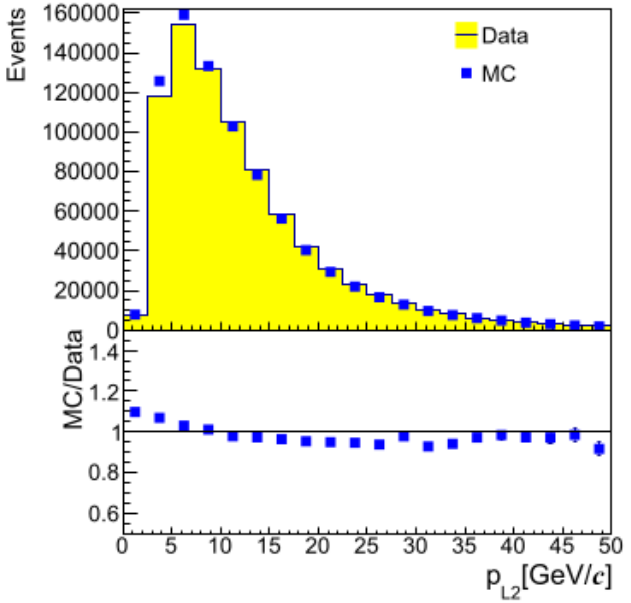




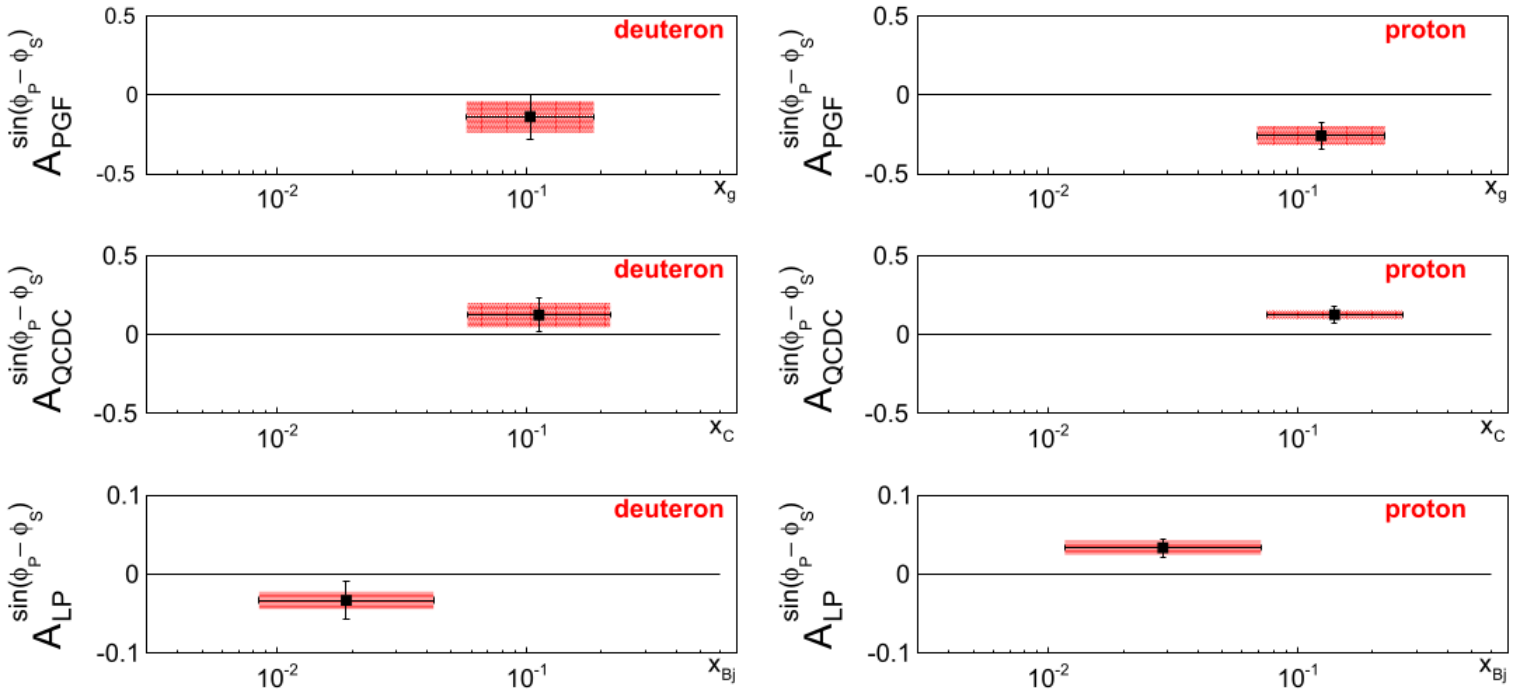








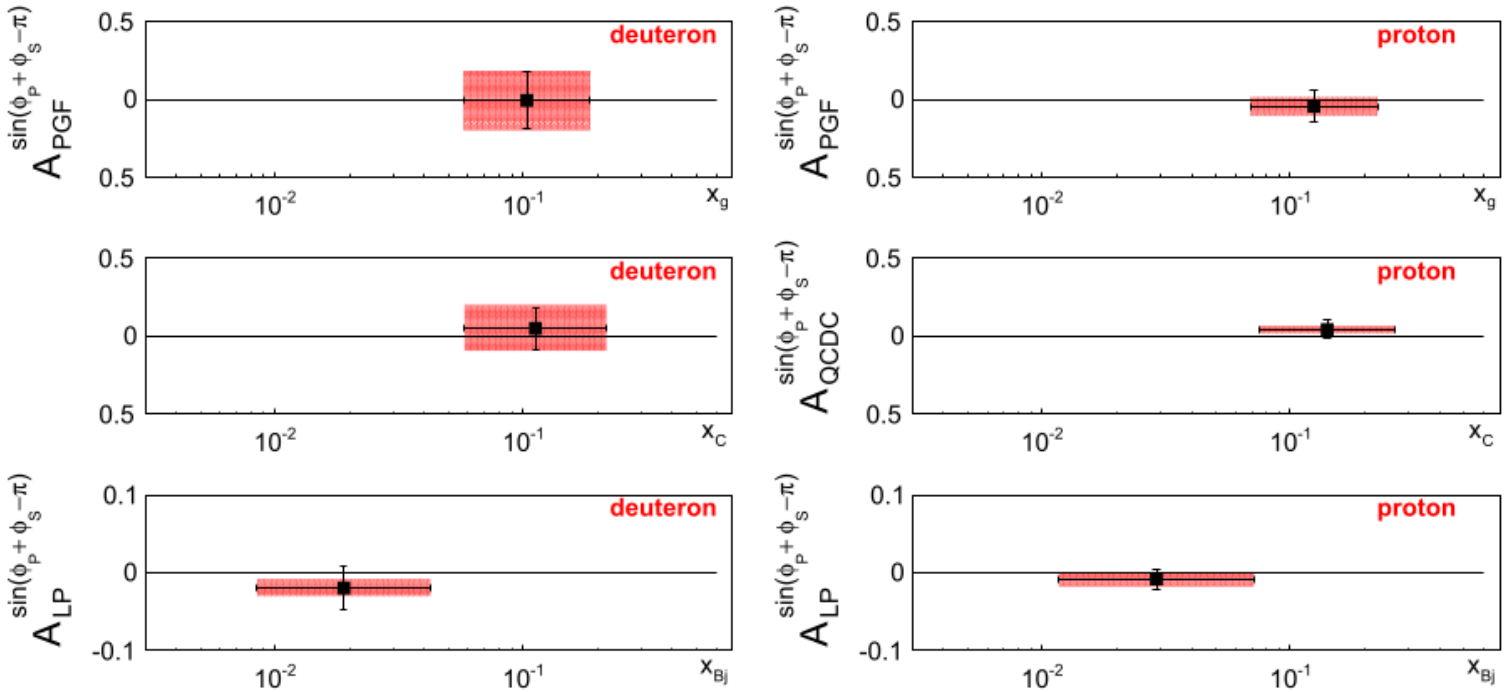
High p_T hadrons: Results



The final Sivers-like asymmetries for deuteron and proton [COMPASS, Phys.Lett.B772 (2017)].

- $A_{\mathrm{PGF,d}}^{\sin\phi_{\mathrm{Siv}}} = -0.14 \pm 0.15(\mathrm{stat.}) \pm 0.06(\mathrm{syst.})$,
- $A_{\mathrm{PGF,p}}^{\sin\phi_{\mathrm{Siv}}} = -0.26 \pm 0.09(\mathrm{stat.}) \pm 0.08(\mathrm{syst.})$
- Combined: $A_{\mathrm{PGF}}^{\sin\phi_{\mathrm{Siv}}} = -0.23 \pm 0.08(\mathrm{stat.}) \pm 0.05(\mathrm{syst.})$
- The results for LP consistent with the standard 1h Sivers asymmetry.
- The main systematic uncertainty: MC settings and tuning.

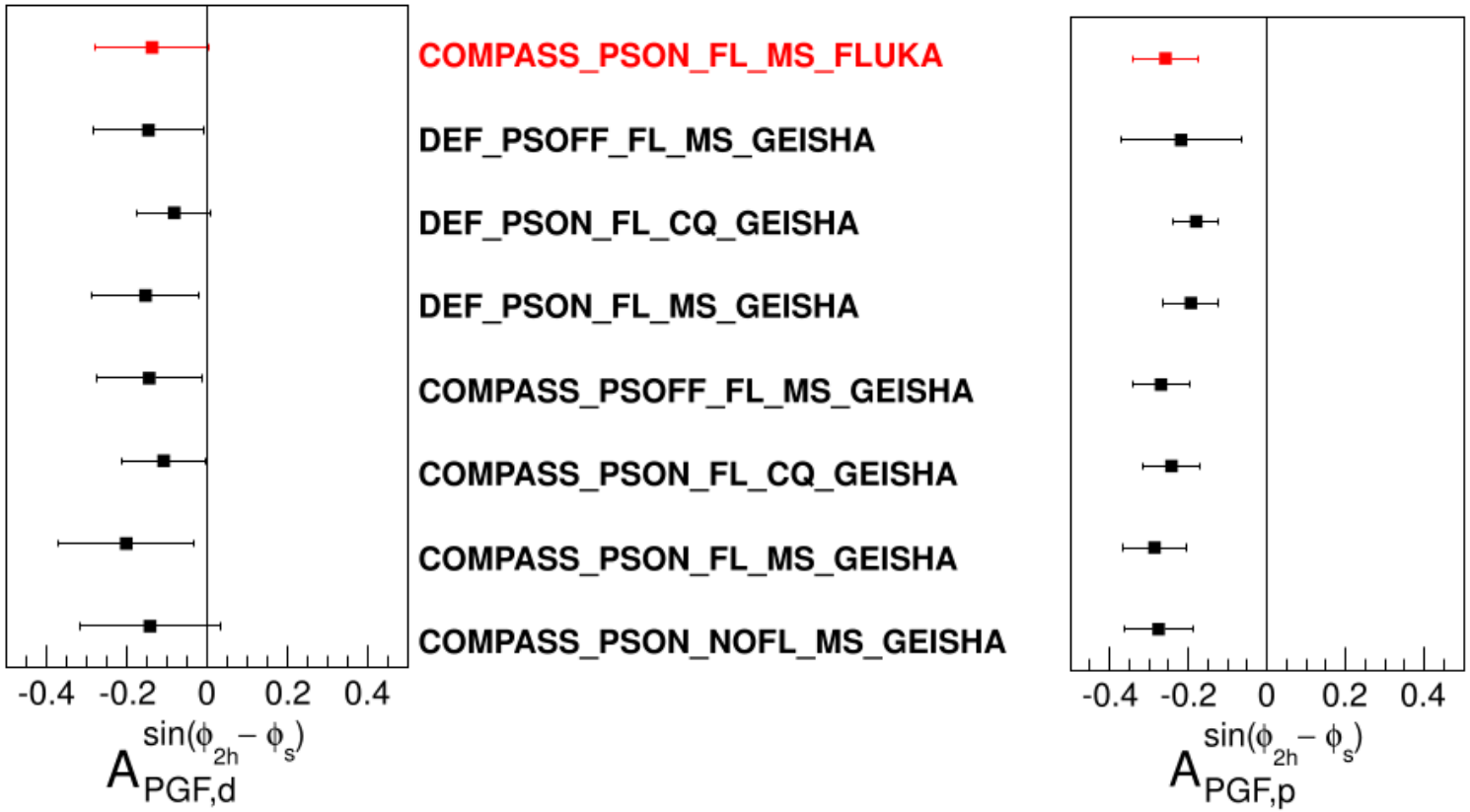
High p_T hadrons: Results



The final Collins-like asymmetries for deuteron and proton [COMPASS, Phys.Lett.B772 (2017)].

- Collins-like asymmetries obtained in the same way.
- For PGF compatible with zero (expected, gluonic transversity being zero).

High p_T hadrons: Results



The dependence of the asymmetries on MC settings [COMPASS, Phys.Lett.B772 (2017)].

- Parton shower on/off,
- F_L from LEPTO or from σ_L/σ_T,
- PDF set variation,
- secondary interaction FLUKA or GEISHA.

Outline

Conclusion, discussion

- The results obtained in muon scattering on transversely polarised nucleons.
- Two methods.
- J/ψ production:
  - Limited statistics, only p target.
  - $A_{\mathrm{Siv}}^{\mathrm{p}} = -0.28 \pm 0.18$ (preliminary).
- Two high-p_{T} hadron production:
  - Analysed using a neural network trained on MC.
  - Compatible results on p and d.
  - Combined: $A_{\mathrm{PGF}}^{\sin\phi_{\mathrm{Siv}}} = -0.23 \pm 0.08(\mathrm{stat.}) \pm 0.05(\mathrm{syst.})$
- The results are consistent.
- They point towards non-zero gluonic Sivers function → orbital angular momentum.

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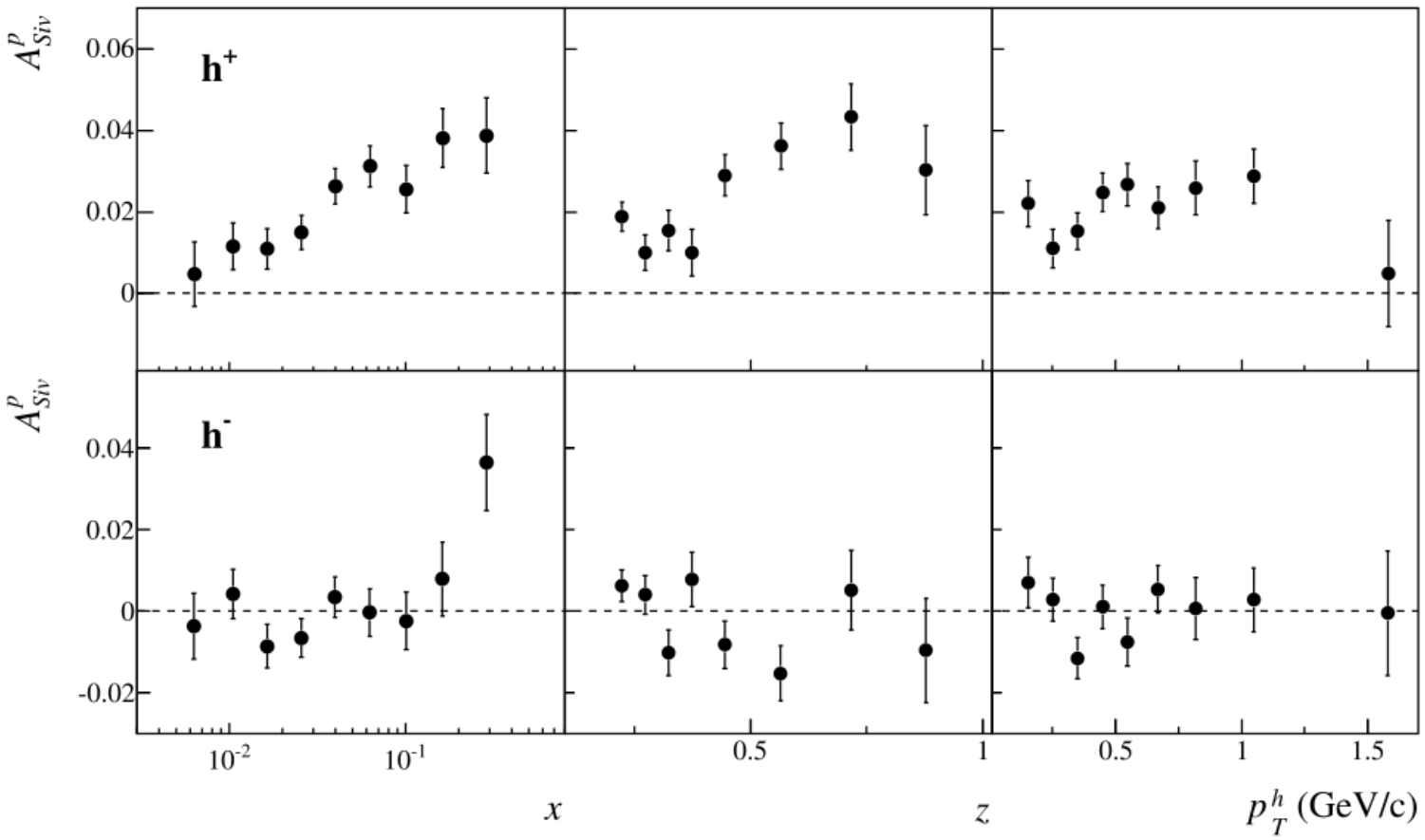
Thank you for your attention!

Backup: Dependence of the LP Sivers asymmetry on p_{T}



The Sivers asymmetry on protons [COMPASS, Phys.Lett.B717 (2012)]. The dependence on p_{T}, and thus the correlation of the LP fraction and the asymmetry, is weak.