The gluon Sivers asymmetry measurements at COMPASS

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on behalf of the COMPASS collaboration

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Outline

Nucleon spin decomposition

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

- $\Delta\Sigma \in [0.26; 036]$

  COMPASS, PLB 753 (2016) 18; E. C. Aschenauer , R. Sassot, M. Stratmann Phys.Rev. D92 (2015)

- $\Delta g/g$ from COMPASS and ΔG from global fit including RHIC data are indecisive about the ΔG contribution

  COMPASS, acc EPJC, hep-ex/1609.06062; COMPASS, PRD87 (2013) 052018; FSSV, PRL 1 113 012001 (2014)

- Nonzero Sivers effect has been measured in SIDIS for positive hadrons

  H. Avakian, A. Bressan, M. Contalbrigo, Eur.Phys.J. A52 (2016) no.6, 150

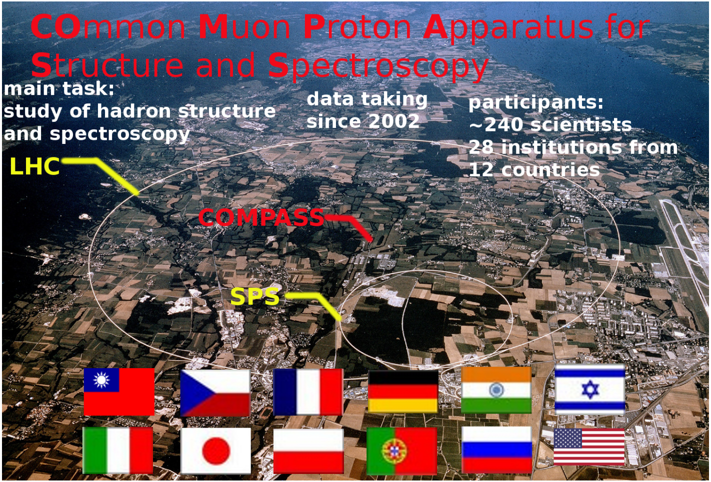
- QCD Lattice calculations and model-dependent data analysis show significant but opposite contribution of L_u and L_d

  LHPC DW, arXiv:1111.0718, (2011); C. Lefky, A. Prokudin, Phys.Rev. D91 (2015) no.3, 034010

- Nonzero Sivers function of gluon can be related to its orbital motion in a polarised nucleon

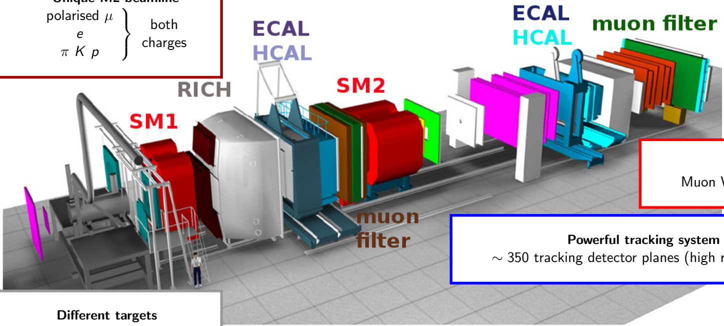
  D. W. Sivers, PRD **41** (1990) 83; D. Boer, C. Lorc, C. Pisano, J. Zhou, Adv.High Energy Phys. 2015 (2015) 371396

COMPASS@CERN



spectrometer

Unique M2 beamline
polarised μ, e, π K p — both charges

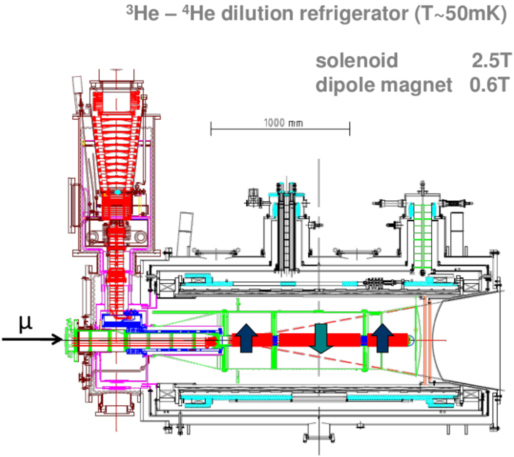


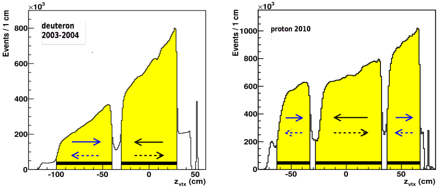
Particle identification
Muon Walls, H/E calorimeters, RICH

Powerful tracking system
$\sim$ 350 tracking detector planes (high redundancy)

Different targets
LiD, NH_3 (polarised)
H_2 and nuclear targets

The COMPASS transversely polarised target

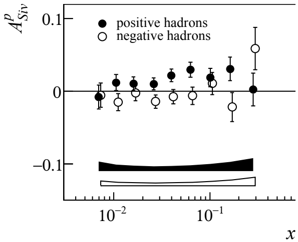




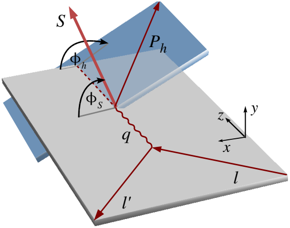
'deuteron' - Li^6D 2 cells
'proton' - NH^3 3 cells

	Li^6D	NH^3
polarisation	50%	90%
dilution	40%	16%

Single hadron Sivers at COMPASS



PLB 692 (2010) 240246



$$\phi_{Siv} = \phi_h - \phi_S$$

$$N_t = \alpha_t(1 + fP_T A^{\sin(\phi_h - \phi_S)} \sin(\phi_h - \phi_S))$$

N_t - expected number of events from the target configuration t

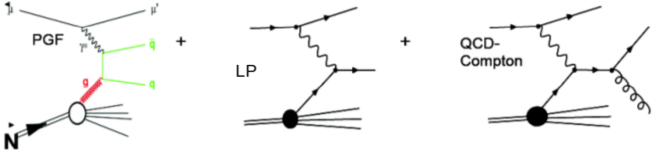
α_t - generalised acceptance

f - dilution factor

P_T - polarisation factor

3 processes

photon-gluon fusion (PGF) | Leading process (LP)- main DIS process | QCD Compton



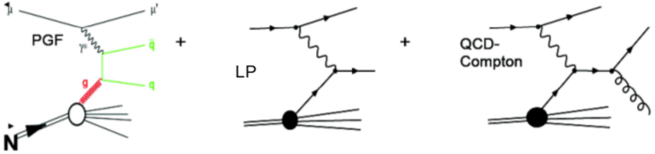
3 processes in the single photon exchange approximation describe well the unpolarised data

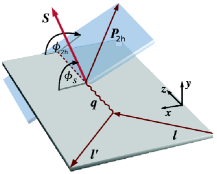
With the use of neural network trained on MC simulation it is possible to extract

the asymmetries of the three processes simultaneously.

Method presented in the $\Delta g/g$ extraction paper: COMPASS, acc EPJC, hep-ex/1609.06062

Tagging the gluons



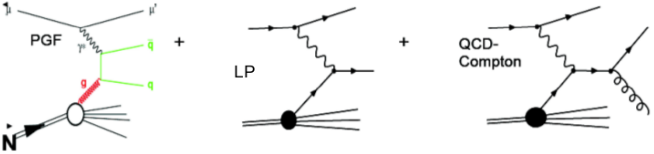


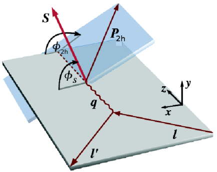
$$\mathbf{P} = \mathbf{p}_1 + \mathbf{p}_2$$
$$\phi = \phi_P - \phi_S$$

$$\phi_{Sivers} \equiv \phi = \phi_P - \phi_S$$

ϕ_P is the azimuthal angle of the sum of **two leading hadron momenta** as this angle should have the strongest correlation with the gluon azimuthal angle (ϕ_g)

3 (single photon exchange) processes





$$\mathbf{P} = \mathbf{p}_1 + \mathbf{p}_2$$
$$\phi = \phi_P - \phi_S$$

$$N_t = \alpha_t \left(1 + \beta_t^G A_{PGF}^{\sin\phi}(\vec{x}) + \beta_t^L A_{LP}^{\sin\phi}(\vec{x}) + \beta_t^C A_{QCDC}^{\sin\phi}(\vec{x})\right) \quad t = ud, c, ud', c'.$$

α_t - generalised acceptance of cell t

$$\beta^G = R_{PGF} f P_T \sin\phi,$$
$$\beta^L = R_{LP} f P_T \sin\phi,$$
$$\beta^C = R_{QCDC} f P_T \sin\phi.$$

$R_{PGF}, R_{LP}, R_{QCDC}$ - from neural network trained on MC data

Data selection

Kinematic cuts

- DIS cuts: $Q^2 > 1(\mathrm{GeV}/c)^2$; $0.003 < x_{Bj} < 0.7$; $0.1 < y < 0.9$;
- $W > 5\mathrm{GeV}/c^2$;
- $z_1, z_2 > 0.1$;
- $z_1 + z_2 < 0.9$;
- $p_{T1} > 0.7\mathrm{GeV}/c$; $p_{T2} > 0.4\mathrm{GeV}/c$ - optimised to enhance PGF fraction and ϕ_g, ϕ_P correlation in MC.

MC used for NN training

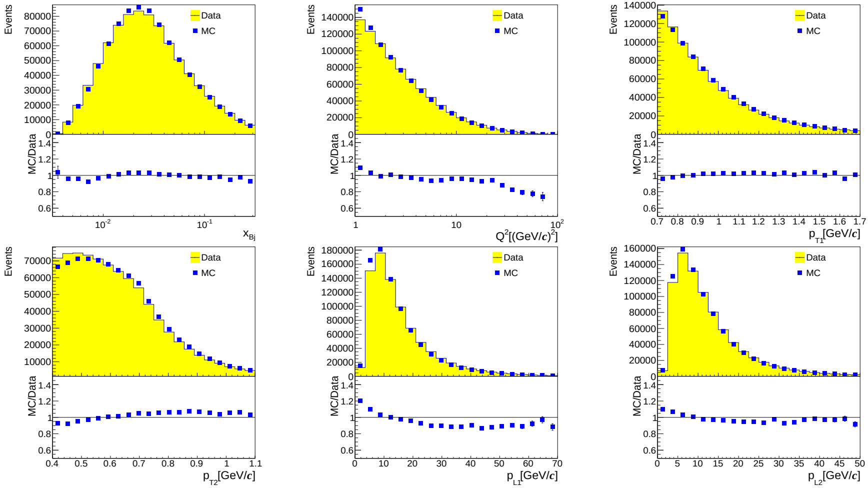
Full chain MC with LEPTO generator, GEANT with COMPASS setup and reconstruction package

- MSTW08 PDFs
- Parton Shower on
- F_L on
- FLUKA for secondary interactions

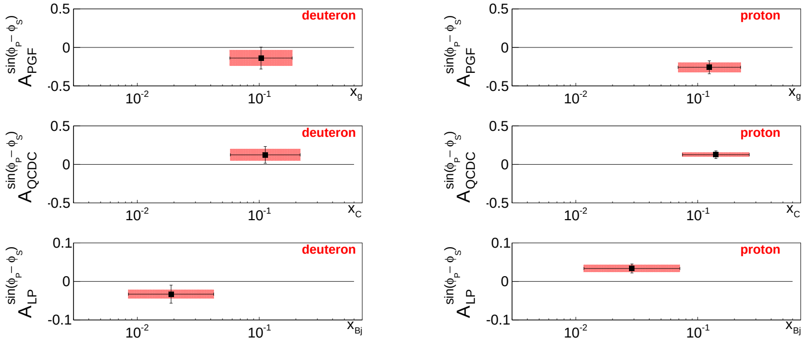
6 kinematic variables as an input of NN: $p_{T1}, p_{T2}, p_{L1}, p_{L2}, Q^2, x_{Bj}$

good agreement between MC and data for distribution of these variables needed

MC vs data. Proton



Sivers

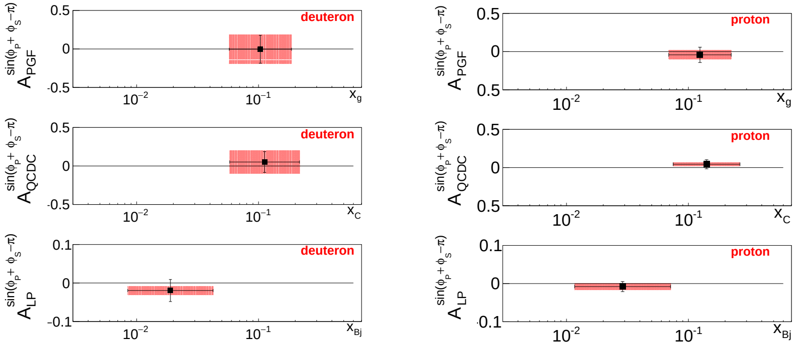


Results

- Gluon Sivers contribution for proton: $A_{PGF,p}^{\sin(\phi_P-\phi_s)} = -0.26 \pm 0.09(stat.) \pm 0.06(syst.)$
- Gluon Sivers contribution for deuteron: $A_{PGF,d}^{\sin(\phi_P-\phi_s)} = -0.14 \pm 0.15(stat.) \pm 0.10(syst.)$
- Limited precision on deuteron. More data needed.
- The results for the LP compatible with single hadron measurements.
- COMPASS,sub PLB, hep-ex/1701.02453.

The analysis is repeated with the Collins angle: $\phi_{Coll} = \phi_P + \phi_S - \pi$

Collins-like

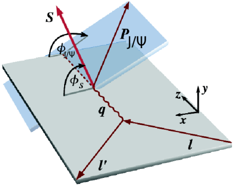


Results

- Gluon Collins-like contribution both for proton and deuteron is compatible with zero
- The results for LP is zero in qualitative agreement with SIDIS single hadron measurement
- COMPASS, sub PLB, hep-ex/1701.02453

Sivers Asymmetry for J/Ψ

$$\mu^+ + N \to \mu^+ + J/\Psi + X \to 2\mu^+ + \mu^- + X$$

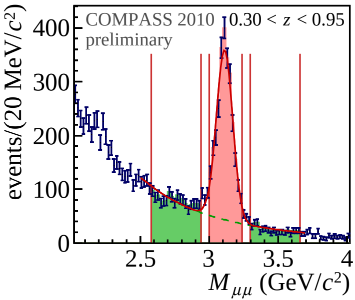


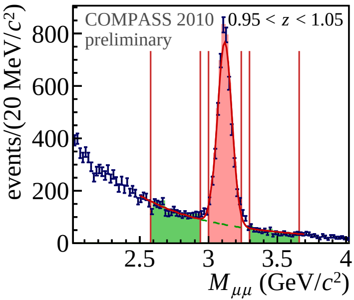
$$\mathbf{P}_{J/\Psi} = \mathbf{p}_{\mu^+} + \mathbf{p}_{\mu^-}$$
$$\phi_{\mu^+\mu^-} = \phi_{J/\Psi} = \phi_g$$

[Godbole, Misra,Mukherjee, and Rawoot, PRD 85 (2012)

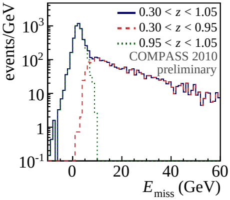
J/Ψ signal

- COMPASS 2010: Clear J/Ψ signal (3.1 GeV/c^2 $\sigma = 55$ MeV/c^2),
- small background, but limited statistics (2300 incl. and 4500 excl.)

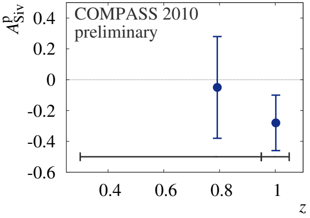




Gluon Sivers from J/Psi results



The missing energy.



The Asymmetry. Black line denotes the integration region.

Results

- $A_p^{Siv} = -0.05 \pm 0.33$ (inclusive J/Ψ).
- $A_p^{Siv} = -0.28 \pm 0.18$ (Exclusive J/Ψ).
- Jan Matousek on behalf of COMPASS, JoP Conf. Series, http://iopscience.iop.org/1742-6596/678/1/012050.
- Prospect for better statistics: max. factor of 2.

Summary

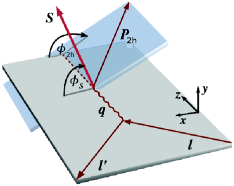
1. The results where obtained for scattering of muons off transversely polarised nucleon targets and selecting a high-p_T hadron pair sample with a complex method including MC simulation and Neural Networks.
2. The results of the gluon Sivers asymmetry for deuteron and proton are compatible within 1σ.
3. Combined deuteron and proton result is 2σ below zero.
4. The results from the J/Ψ analysis suffer from large statistical error.
5. For more details see hep-ex/1701.02453 and
http://wwwcompass.cern.ch/compass/publications/theses/2016_phd_szabelski.pdf

Backup slides

Sivers Asymmetry for hadron pairs

Nonzero Sivers function of gluon can be related to its orbital motion in a polarised nucleon

$$\ell + N \rightarrow \ell' + 2h + X$$



$$\mathbf{P}_P = \mathbf{p}_1 + \mathbf{p}_2$$
$$\mathbf{R} = \frac{1}{2}(\mathbf{p}_1 - \mathbf{p}_2)$$

ϕ_P for gluons correlated to ϕ_g (from MC)

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

σ- two-hadron cross-section integrated over ϕ_R;

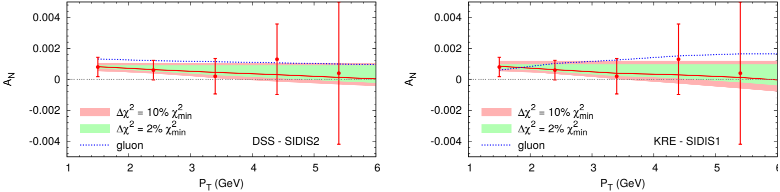
$$A_T^P(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)}$$

$$N(\phi) = an\Phi\sigma_0(1 + P_T f A^{\sin(\phi)} \sin(\phi))$$

Phys.Rev.Lett.**113**, 062003 (2014); Phys. Rev. D **90**, 074006 (2014); JHEP (2016), hep-ph/1605.07934

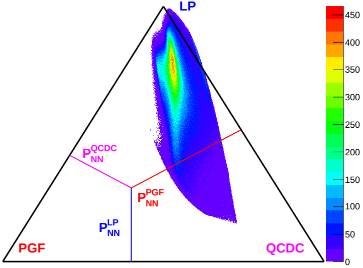
Gluon Sivers measurements

- Gluon Sivers from $pp^{\uparrow}$ collisions at PHENIX@RHIC.

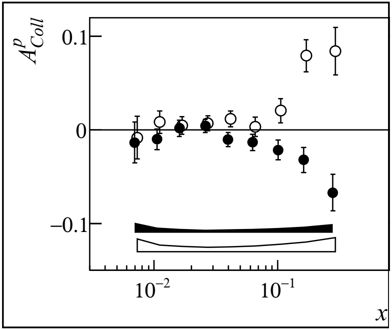


U. DAlesio, F. Murgia and C. Pisano JHEP 1509 (2015) 119

Neural network output

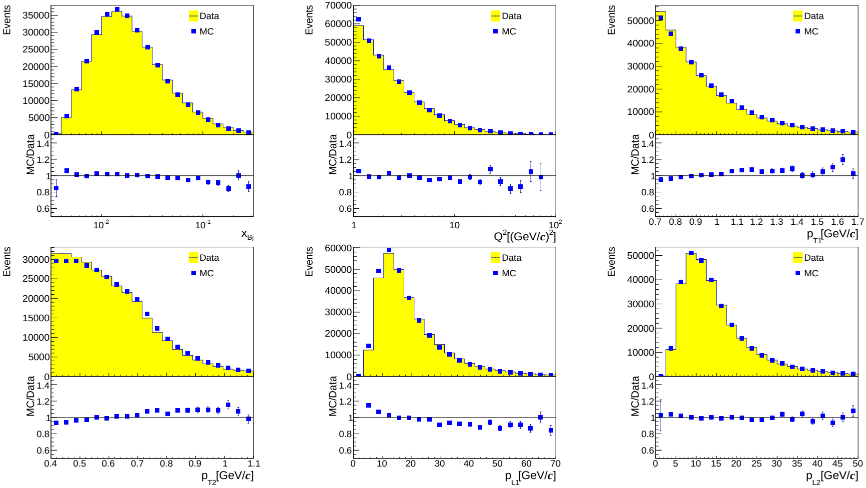


'Standard' Collins. proton



PLB 692 (2010) 240246

MC vs data. Deuteron



Weighting method. 3 processes

$$N_t = \alpha_t^j \Big(1 + \beta_t^G A_{PGF}^{\sin\phi}(\vec{x}) + \beta_t^L A_{LP}^{\sin\phi}(\vec{x}) + \beta_t^C A_{QCDC}^{\sin\phi}(\vec{x}) \Big) \qquad t = ud, c, ud', c'.$$

$$p_t^j := \int \omega^j(\phi) N_t(\vec{x}) d\vec{x} \approx \sum_{i=1}^{N_t} \omega_i^j$$

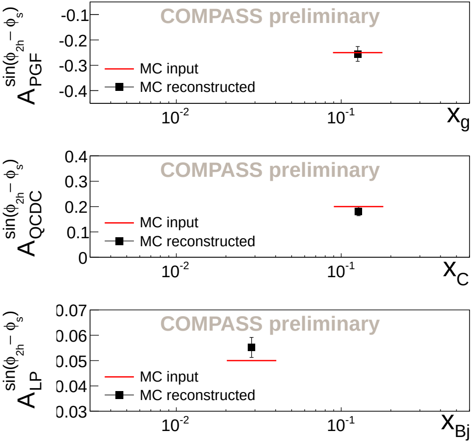
$$= \tilde{\alpha}_t^j \Big(1 + \{\beta_t^G\}_{\omega^j} A_{PGF}^{\sin\phi}(\langle x_g \rangle) + \{\beta_t^L\}_{\omega^j} A_{LP}^{\sin\phi}(\langle x_{Bj} \rangle) + \{\beta_t^C\}_{\omega^j} A_{QCDC}^{\sin\phi}(\langle x_C \rangle) \Big).$$

$$\{\beta_t^G\}_{\omega^j} = \frac{\int \alpha_t \beta_t^G \omega^j d\vec{x}}{\int \alpha_t \omega d\vec{x}} \approx \frac{\sum_i^{N_t} \beta_i^G \omega_i^j}{\sum_i^{N_t} \omega_i^j}$$

Here $j = PGF, LP, QCDC$ and $\frac{\tilde{\alpha}_{ud}^j \tilde{\alpha}_{c'}^j}{\tilde{\alpha}_{ud'}^j \tilde{\alpha}_c^j} = 1$ limits the number of unknowns to 12.

The set of equations is solved by minimising the χ^2

Method Validation

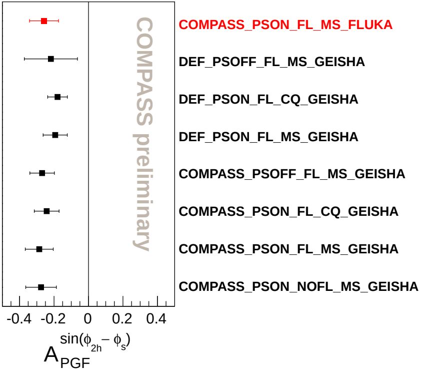


Systematics summary.

	deuteron			proton		
source	value	assigned error	% $\sigma_{stat}(= 0.15)$	value	assigned error	% $\sigma_{stat}(= 0.085)$
Monte Carlo	0.060	0.060	40%	0.054	0.054	64%
False asymmetries	0.016	0	0%	0.032	0	0%
selection of charges $q_1 \cdot q_2 = -1$	0.05	0	0%	0.038	0	0%
radiative corrections	0.018	0.018	12%	0.018	0.018	21%
large Q^2	-	-	-	0.014	0	0%
x_{Bj} binning	0.07	0.07	47%	0.011	0.011	13%
all asyms vs only Sivers	0.003	0.003	2%	0.005	0.005	6%
ML vs Weighted	0.008	0	0%	0.004	0	0%
target polarisation	0.0075	0.0075	5%	0.0043	0.0043	5%
dilution factor	0.0075	0.0075	5%	0.0043	0.0043	5%
total $\sqrt{\sum \sigma_i^2}$	-	0.10	63%	-	0.06	69%

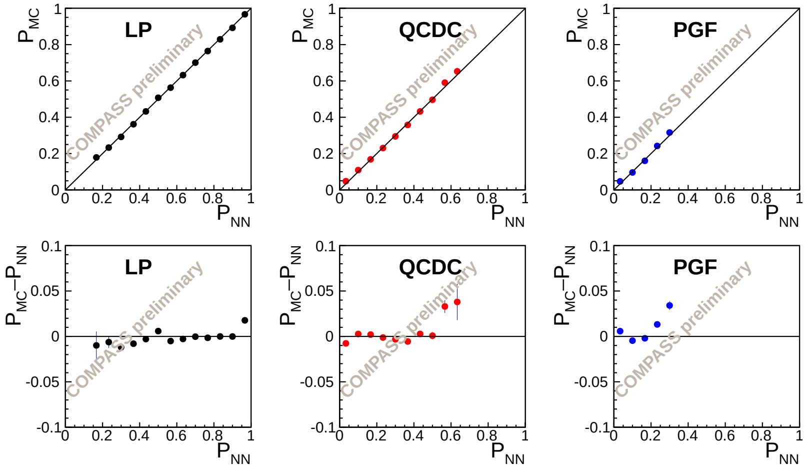
Table : Systematics summary.

NNs final



RMS : 0.040; min : -0.300; max : -0.193; (max-min)/2 = 0.054

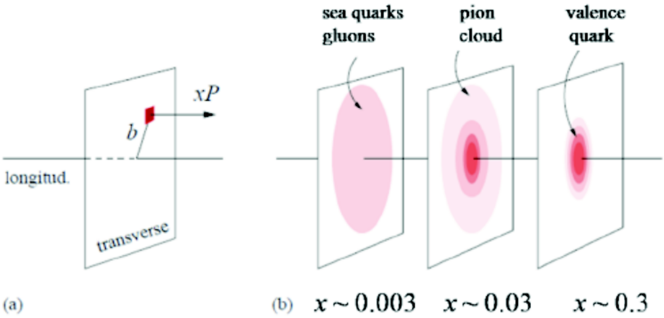
NN training validation



Nucleon "tomography"

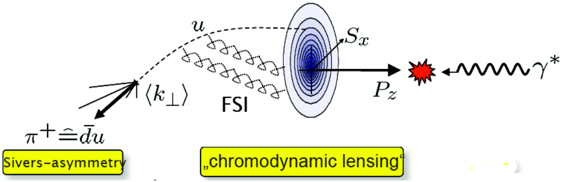
TMD: longitudinal momentum x and transverse momentum $\vec{k}_T$(3D)

alternatively: GPDs gives simultaneous distribution of quarks w.r.t.: longitudinal momentum xP and transverse position $\vec{b}_\perp$- impact parameter (3D)



Chromodynamic lensing

Burkardt model:



$$q_{\hat{x}}(x, \vec{b}_\perp) = \mathcal{H}(x, \vec{b}_\perp) - \frac{1}{2M}\frac{\partial}{\partial b_y}\mathcal{E}(x, \vec{b}_\perp)$$

$\mathcal{H}$ - unpolarised GPD function (symmetric)
$\mathcal{E}$ - spin-flip function, when nonzero $\Rightarrow$ nonzero OAM

M. Burkardt, Int. J. Mod. Phys. A 18 (2003) 173; Nucl. Phys. A 735 (2004) 185; Phys. Rev. D 69 (2004) 074032