The gluon Sivers asymmetry measurements at COMPASS

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DIS16
DESY, HAMBURG 11-15 APRIL 2016

Outline

Nucleon spin

COMPASS

Gluon Sivers from J/Ψ

Gluon Sivers from high-p_T hadron pairs

Summary

Nucleon spin decomposition

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

- $\Delta\Sigma \approx 0.3$

  (The COMPASS Collaboration, V.Yu. Alexakhin *et al.*, Phys. Lett. B 647,8 (2007))

- $\Delta g/g$ from COMPASS and ΔG from global fit to RHIC data suggest small ΔG contribution

  Marcin Stolarski on behalf of the COMPASS Collaboration, PoS (DIS2014) 211

  The COMPASS Collaboration, C. Adolph *et al.*, Phys. Rev. D 87 (2013) 052018

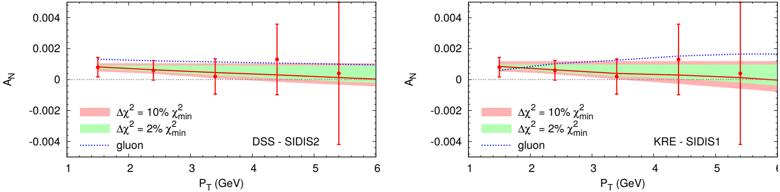
  D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, Phys.Rev.Lett. 1 113 012001 (2014)

- QCD Lattice calculations show significant but opposite contribution of L_u and L_d LHPC DW, S. N. Sirytsyn et al., arXiv:1111.0718, (2011)

- Nonzero Sivers function of gluon can be related to its orbital motion in a polarised nucleon D. W. Sivers, Phys. Rev. D **41** (1990) 83

Gluon Sivers measurements

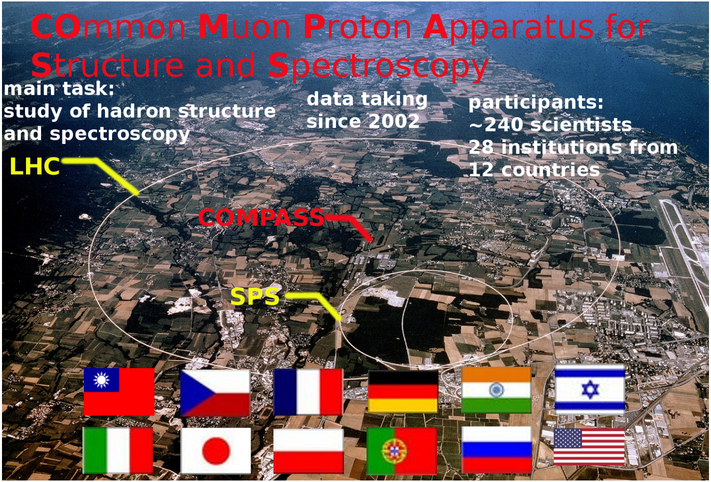
- Gluon Sivers from $pp^{\uparrow}$ collisions at PHENIX@RHIC.



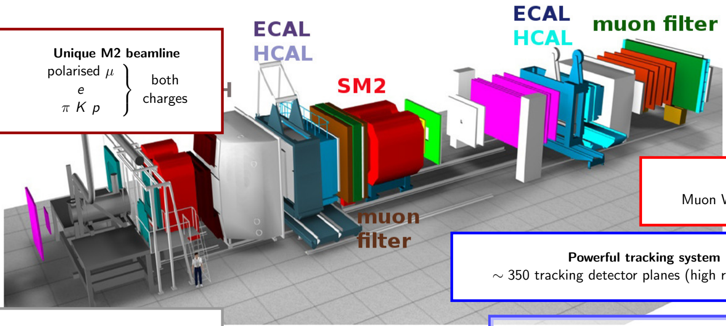
U. DAlesio, F. Murgia and C. Pisano JHEP 1509 (2015) 119

- J/Ψ muoproduction at COMPASS.
- high-p_T hadron pair production at COMPASS.

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)

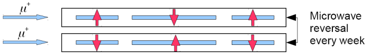
Flexible target area

LiD, NH_3 (polarised)

H_2 and nuclear targets

Two 30cm and one 60 cm long target cells [two 60cm long cells in 2002-2004] with opposite polarization

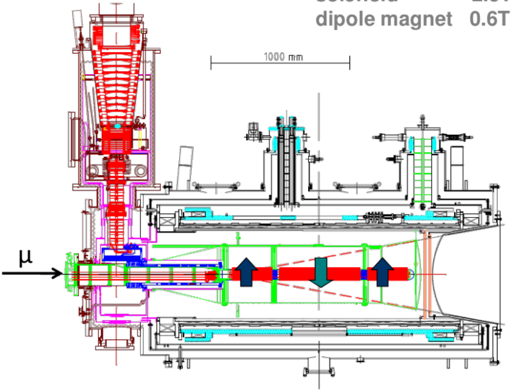
material:	NH_3 (protons)	[^{6}LiD (deuterons)]
polarization:	≈90%	[≈50%]
dilution factor for exclusive ρ^0 production:	≈25%	[≈44%]

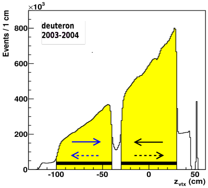


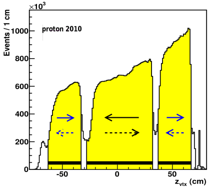
The COMPASS target

^3He – ^4He dilution refrigerator (T~50mK)

solenoid 2.5T
dipole magnet 0.6T







acceptance > ± 180 mrad

3 target cells
30, 60, and 30 cm long

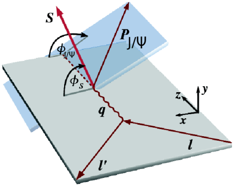
opposite polarisation

	d (^6LiD)	p (NH_3)
polarization	50%	90%
diliution factor	40%	16%

Sivers Asymmetry for J/Ψ

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

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



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

$$\phi = \phi_{\mu^+\mu^-} - \phi_S$$

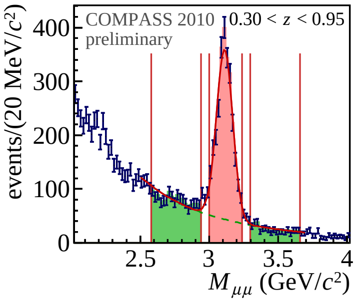
$$A_T^{\mu^+\mu^-}(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)}$$

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

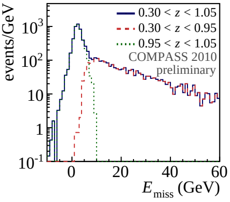
[Godbole, Misra,Mukherjee, and Rawoot, Phys. Rev. D 85 (2012), http://arxiv.org/abs/1201.1066]

J/Ψ signal

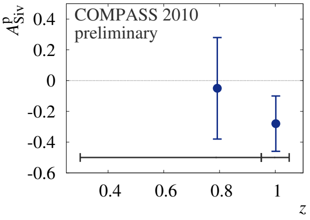
- COMPASS 2010: Clear J/Ψ signal (3.1 GeV/c^2 $\sigma = 55$ MeV/c^2),
- small background, but limited statistics (2300 incl. and 4500 excl.)



Gluon Sivers from J/Psi results



The missing energy.



The Asymmetry. Black line denotes the integration region.

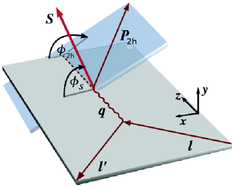
Results

- $A_p^{Siv} = -0,05 \pm 0.33$ (inclusive J/Ψ).
- $A_p^{Siv} = -0,28 \pm 0.18$ (Exclusive J/Ψ).
- COMPASS, JoP Conf. Series, http://iopscience.iop.org/1742-6596/678/1/012050.
- Prospect for better statistics: max. factor of 2.

Sivers Asymmetry for hadron pairs

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

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



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

ϕ_{2h} for gluons correlated to ϕ_g (from MC)

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

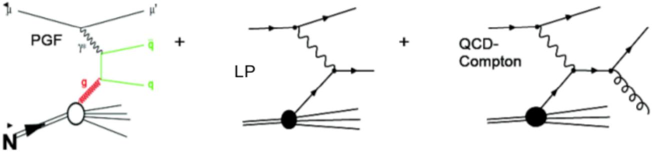
σ- two-hadron cross-section integrated over ϕ_R; $\quad A_T^{2h}(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)}$

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

Phys.Rev.Lett.**113**, 062003 (2014), Phys. Rev. D **90**, 074006 (2014)

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

the analysis procedure

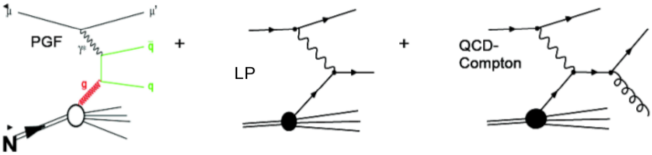
The aim is:

- The extraction of the asymmetry of the photon gluon fusion (PGF) process (signal) and the asymmetries of the leading process (LP) (background 1) and of the QCD Compton process (background 2) from measured Sivers asymmetry

The procedure:

- Selection of events with high-p_T hadron pair sample in order to:
  - enhanced the fraction of PGF events in the sample (too strong cut leads to minimal statistics)
  - have a stronger correlation between the gluon azimuthal angle and the azimuthal angle of the $\mathbf{p}_1 + \mathbf{p}_2$ (ϕ_{2h}) is stronger(from MC)
- assignment of 3 weights to every event (corresponding to the 3 processes) by a neural network (NN) trained on MC data
- Solve the set of equations to obtain the asymmetries for the 3 processes

3 (single photon exchange) processes



$$A_{UT}^{\sin\phi} = R_{PGF} A_{PGF}^{\sin\phi}(\langle x_g \rangle) + R_{LP} A_{LP}^{\sin\phi}(\langle x_{Bj} \rangle) + R_{QDCD} A_{QCDC}^{\sin\phi}(\langle x_C \rangle).$$

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

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

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

Data selection

Kinematic cuts

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

MC used for NN training

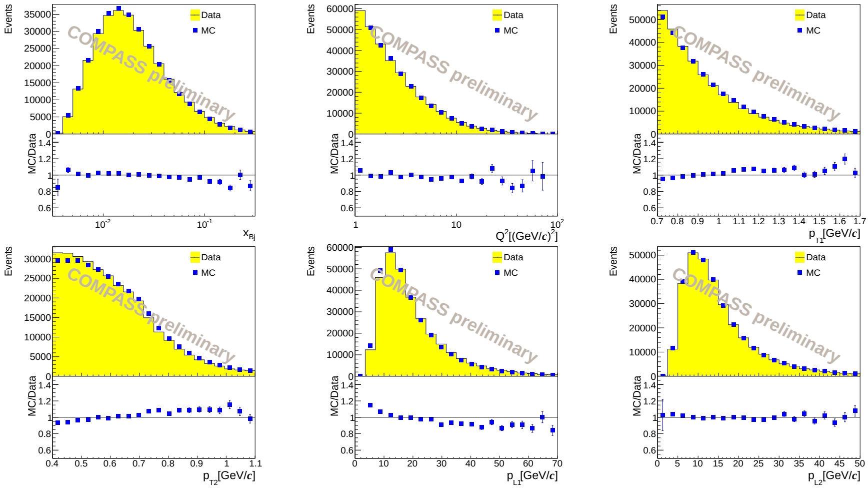
Full chain MC with LEPTO generator, GEANT with COMPASS setup and reconstruction package

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

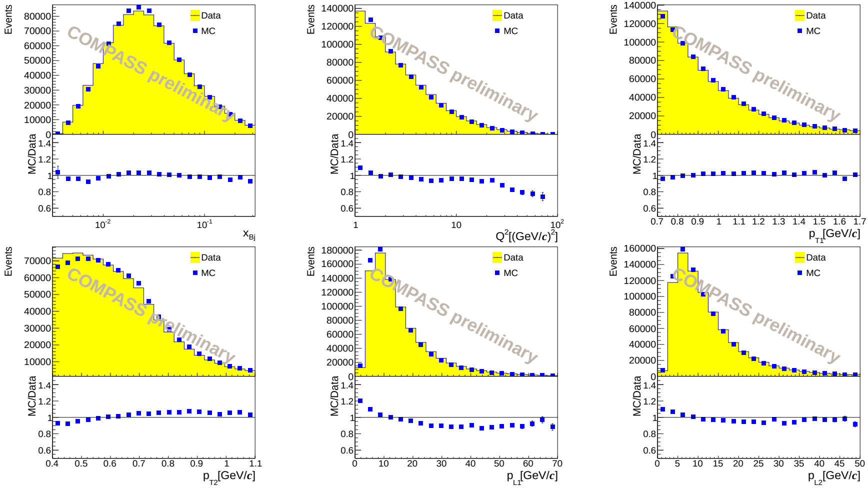
6 kinematic variables as an input of NN: $p_{T1}, p_{T2}, p_{L1}, p_{L2}, Q^2, x_{Bj}$

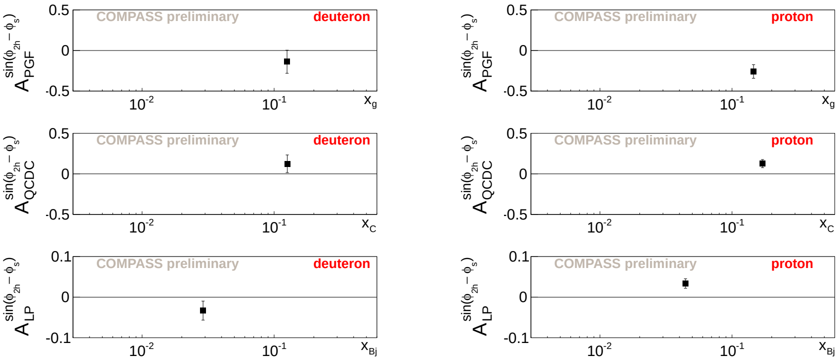
good agreement between MC and data for distribution of these variables needed

MC vs data. Deuteron



MC vs data. Proton





Results

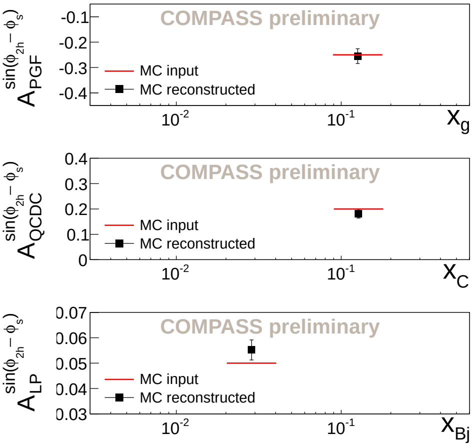
- Gluon Sivers asymmetry for proton: $A_{PGF,p}^{\sin(\phi_{2h}-\phi_s)} = -0.26 \pm 0.09(stat.) \pm 0.06(syst.)$ at $\langle x_G \rangle = 0.15$.
- Gluon Sivers asymmetry for deuteron: $A_{PGF,d}^{\sin(\phi_{2h}-\phi_s)} = -0.14 \pm 0.15(stat.) \pm 0.10(syst.)$ at $\langle x_G \rangle = 0.13$.
- Limited precision on deuteron. More data needed.
- The results for the LP compatible with single hadron measurements.
- COMPASS, J.Phys.Conf.Ser. 678 (2016) no.1, 012055 (http://iopscience.iop.org/1742-6596/678/1/012055).

Summary

1. Two methods of gluon Sivers measurements have been performed at COMPASS.
2. The J/Ψ selection method give negative values but suffers from low statistics.
3. The high-p_T hadron pair method:
    - The result on deuteron is compatible with zero but the central value is negative with large error.
    - 2010 proton data show a value which is negative (3σ from 0).

Backup slides

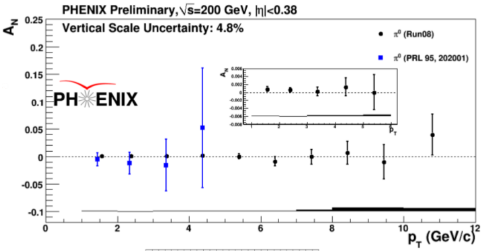
Method Validation



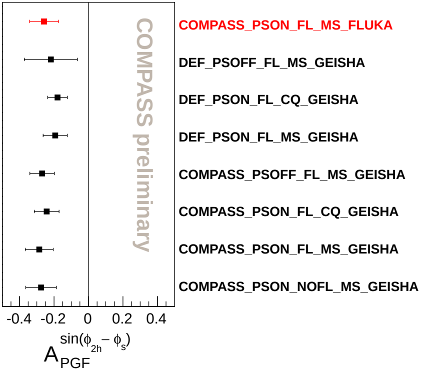
Systematics summary.

	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.

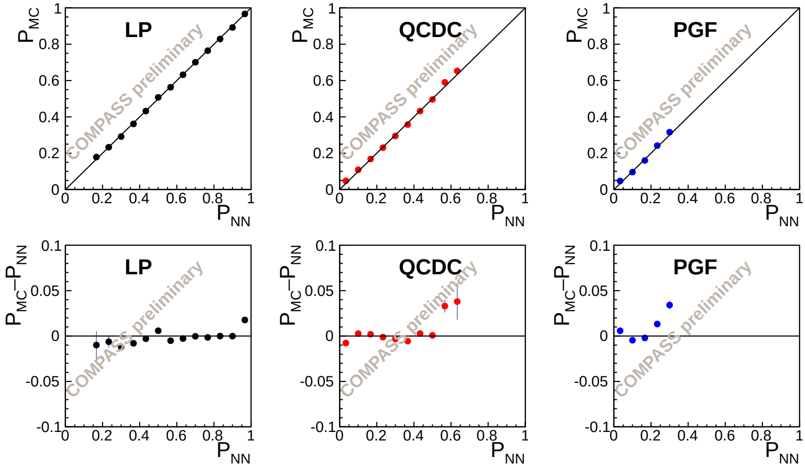

PHENIX Preliminary, √s=200 GeV, |η|<0.38
Vertical Scale Uncertainty: 4.8%
π⁰ (Run08)
π⁰ (PRL 95, 202001)
PHENIX
A_N
p_T (GeV/c)

NNs final



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

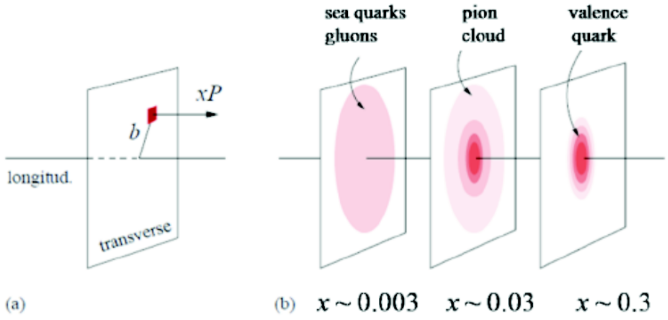
NN training validation



Nucleon "tomography"

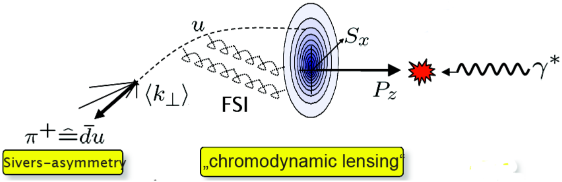
TMD: longitudinal momentum x and transverse momentum $\vec{k}_T$(3D)

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