Gluon Contribution to the Sivers Effect COMPASS Results

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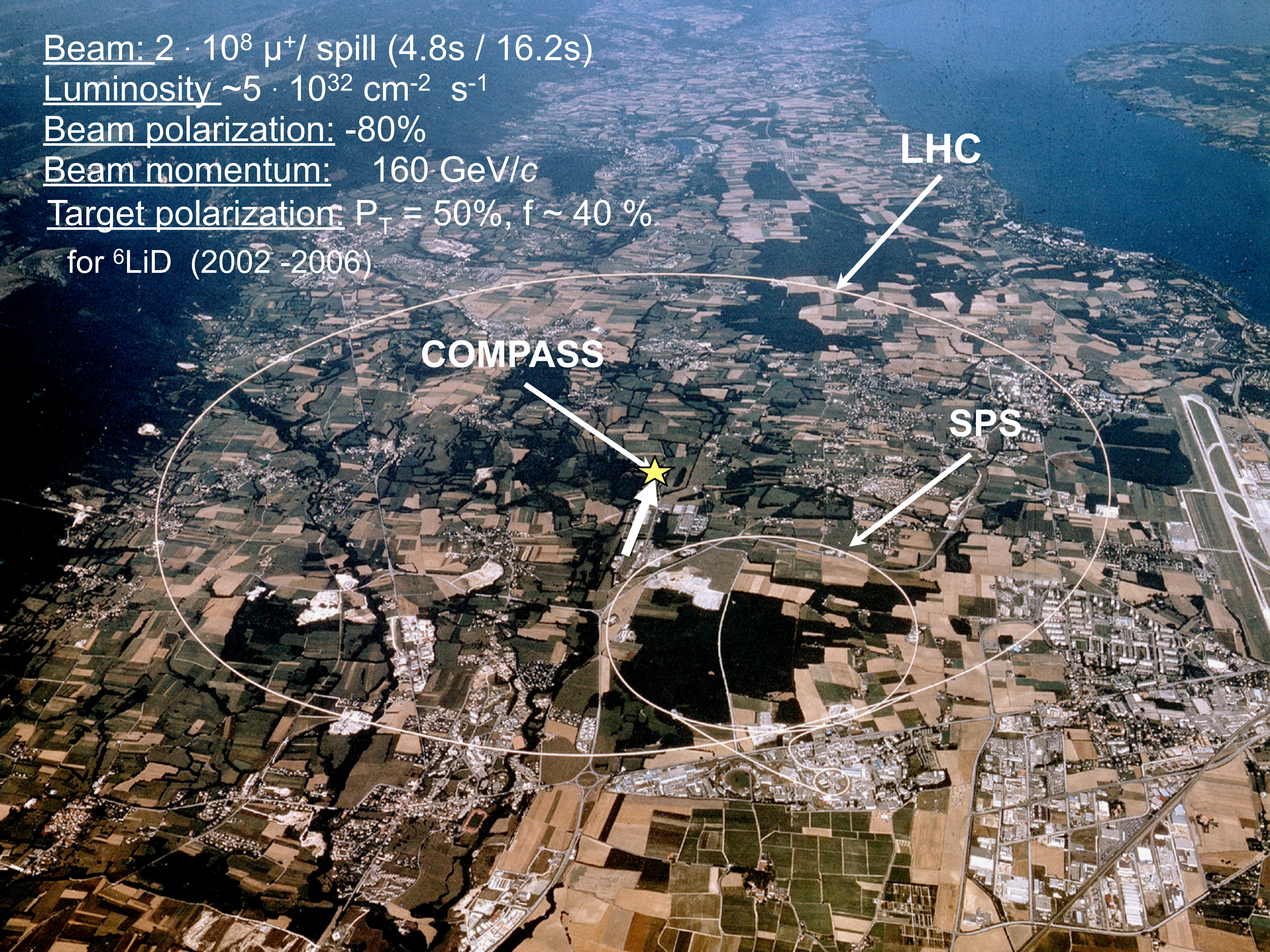
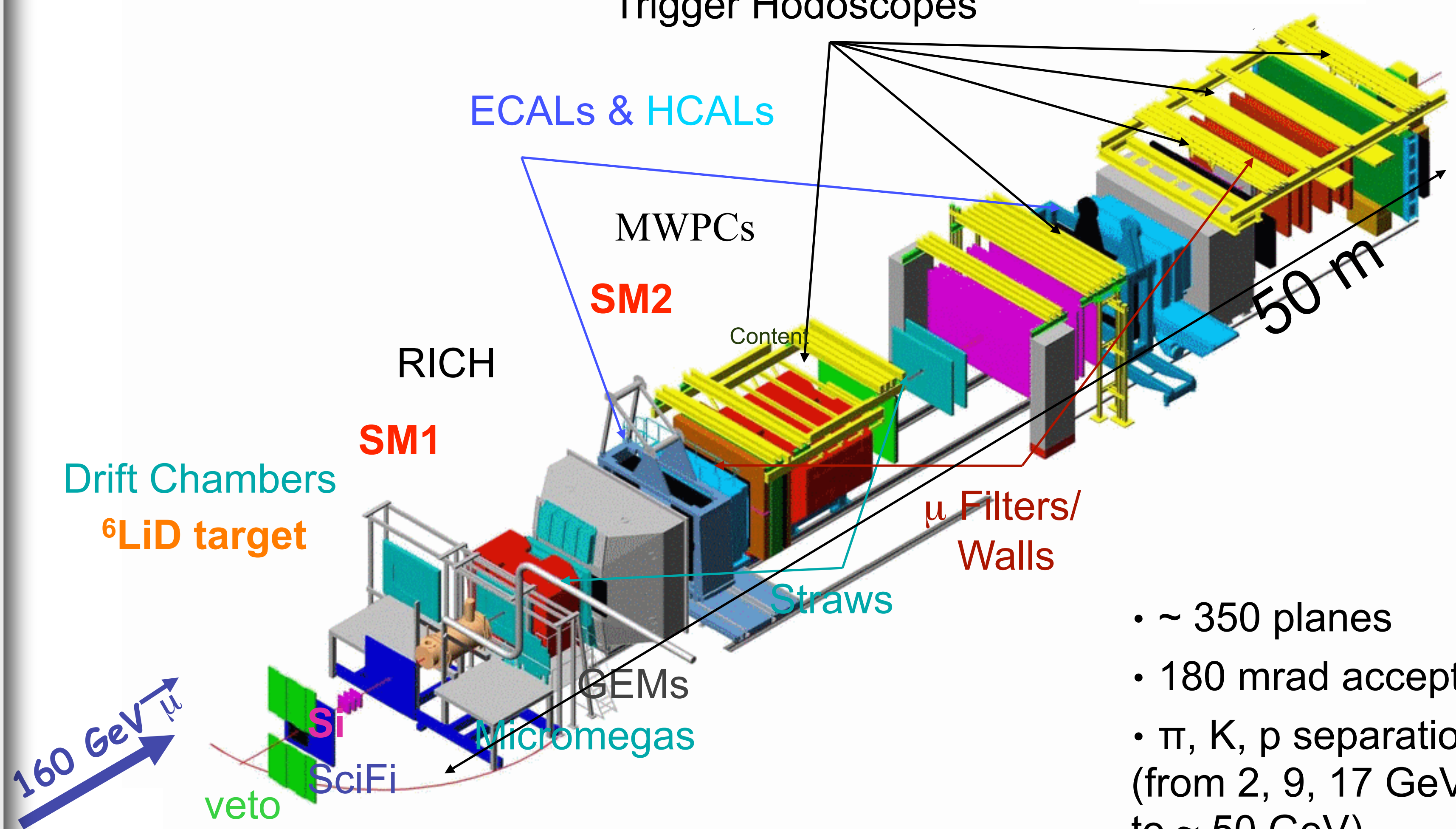
XVI Workshop on High Energy Spin Physics, DSPIN-15
Dubna, Russia, September 8-12


Beam: $2 \cdot 10^{8}$ μ^{+}/ spill (4.8s / 16.2s)
Luminosity $\sim 5 \cdot 10^{32}$ cm^{-2} s^{-1}
Beam polarization: -80%
Beam momentum: 160 GeV/c
Target polarization: P_T = 50%, f ~ 40 %
for ^{6}LiD (2002 -2006)
LHC
COMPASS
SPS

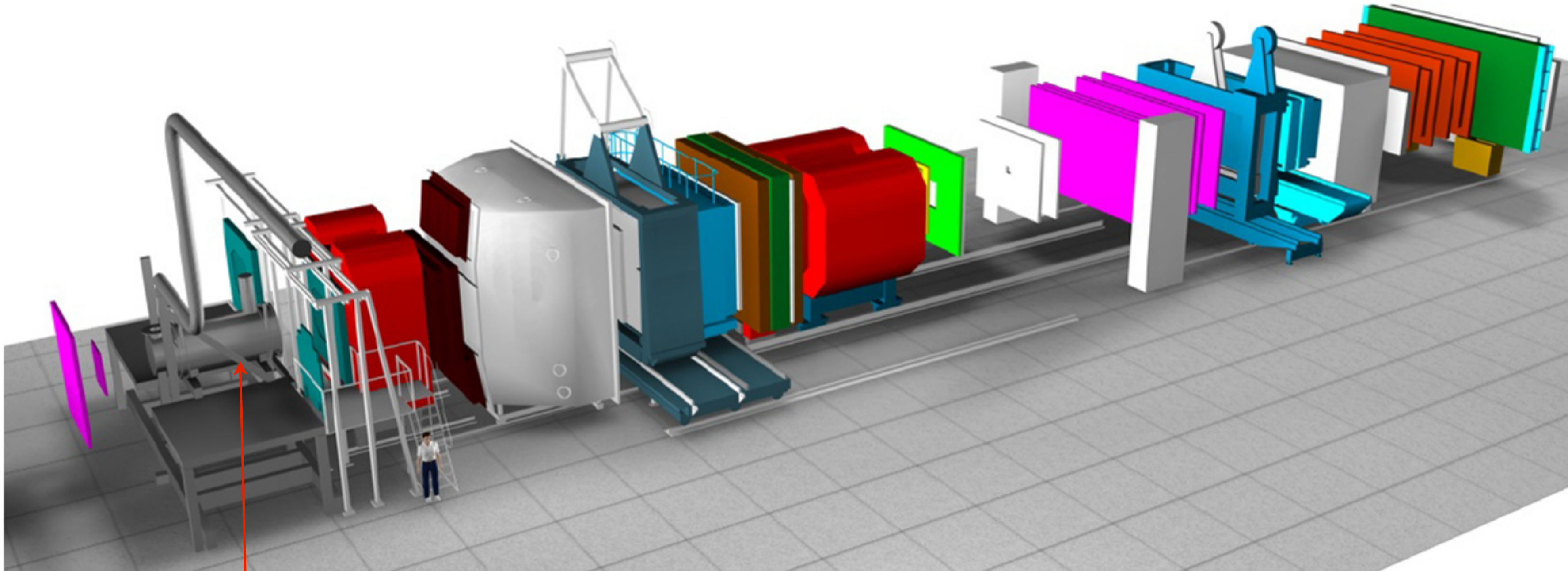
The COMPASS spectrometer

COMPASS in muon run
NIM A 577(2007) 455



- ~ 350 planes
- 180 mrad acceptance
- π, K, p separation (from 2, 9, 17 GeV up to ~ 50 GeV)

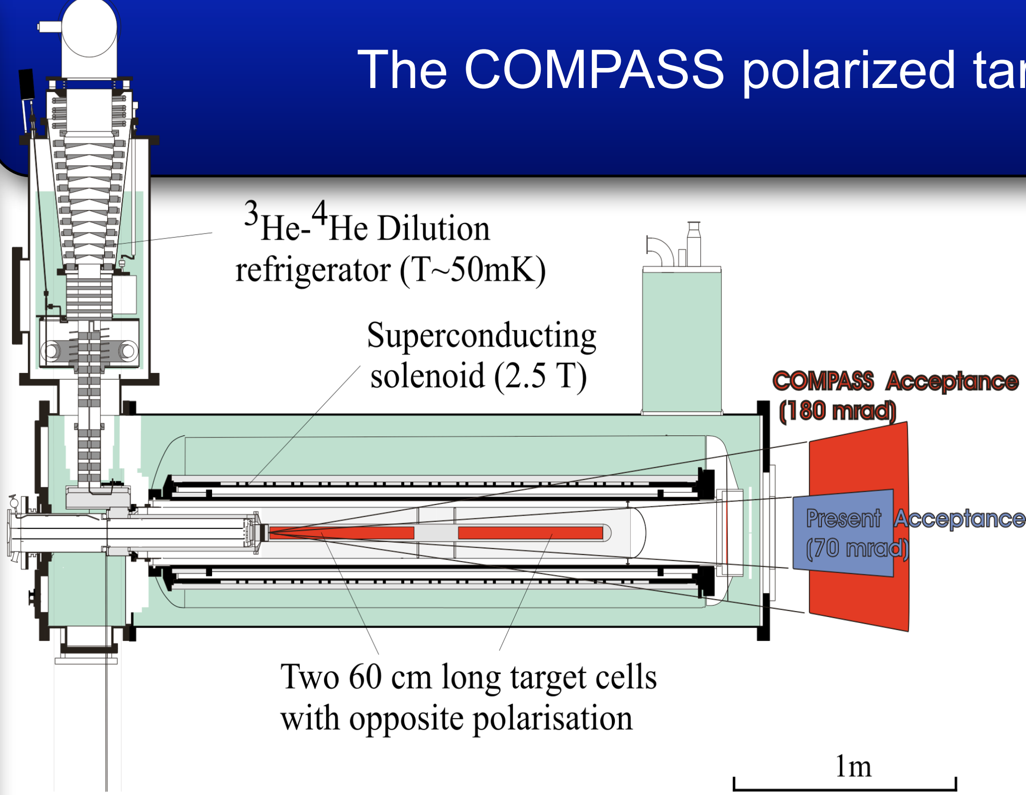
The COMPASS spectrometer



polarised target

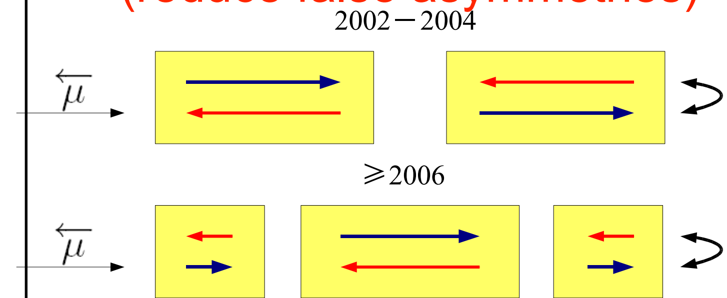
- ~ 350 planes
- 180 mrad acceptance
- π, K, p separation (from 2, 9, 17 GeV up to ~ 50 GeV)

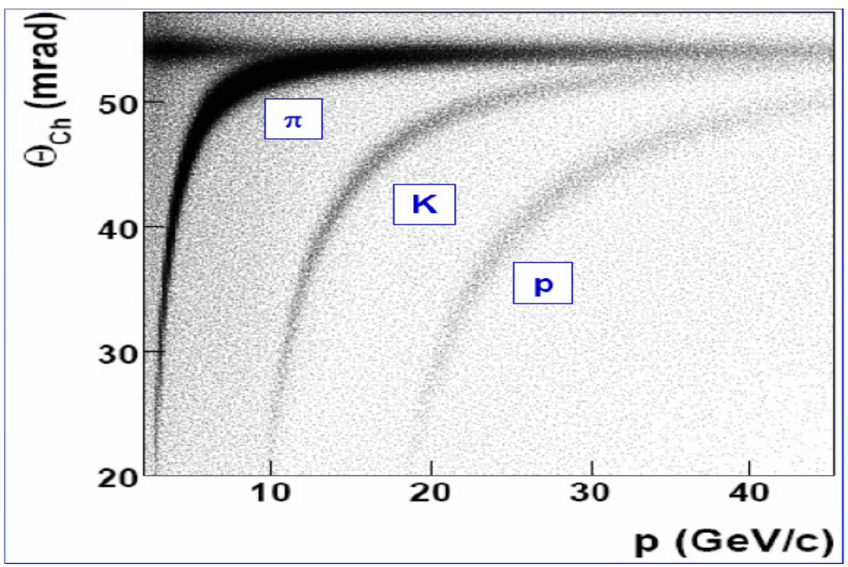
The COMPASS polarized target and PID



Target material: ^{6}LiD
Polarisation: >50%
Dilution factor: ~0.4
Dynamic Nuclear Polarization

2006 - new solenoid
with acceptance 180 mrad
3 target cells
(reduce false asymmetries)





RICH 2006 upgrade : better PID

MAPMTs in central region

APV electronics in periphery

Content

- Introduction
- Gluon „Sivers efect" measurement @ COMPASS
- Artificial Neural Network approach
- Data and Monte Carlo comparison
- Validation of the method - MC data
- Data selection
- Preliminary results on deuteron target
- Preliminary results on proton target
- Systematic studies
- Summary

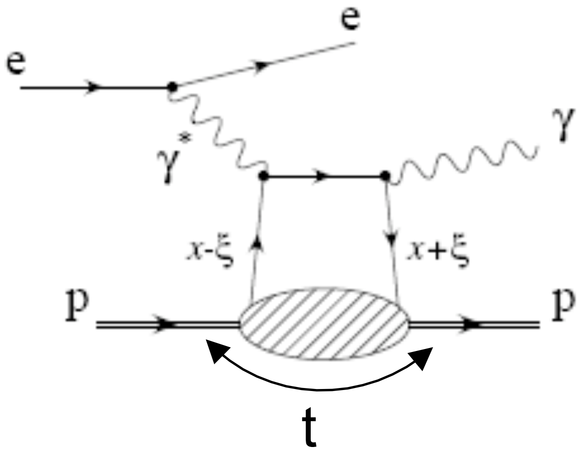
A catalog of PDFs

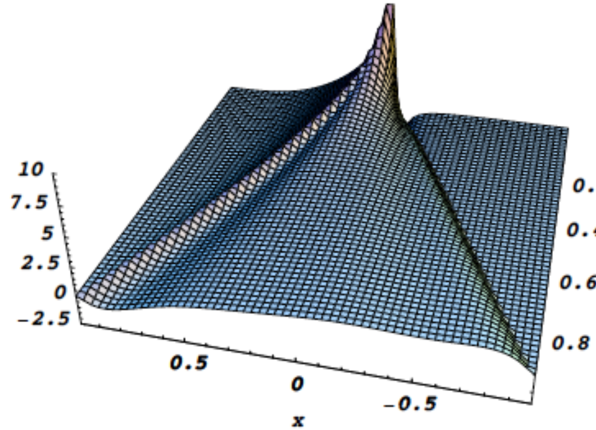
Beyond collinear approximation - k_T dependence

quark polarization \ nucleon polarization	U	L	T
U	f_1 number density		$f_{1T}^{\perp}$ Sivers T-odd
L		g_1 helicity	g_{1T} Worm-gear
T	$h_1^{\perp}$ Boer-Mulders T-odd	$h_{1L}^{\perp}$	h_1 transversity; Pretzelosity $h_{1T}^{\perp}$

LO, twist-2 - 8 independent functions to parameterize structure

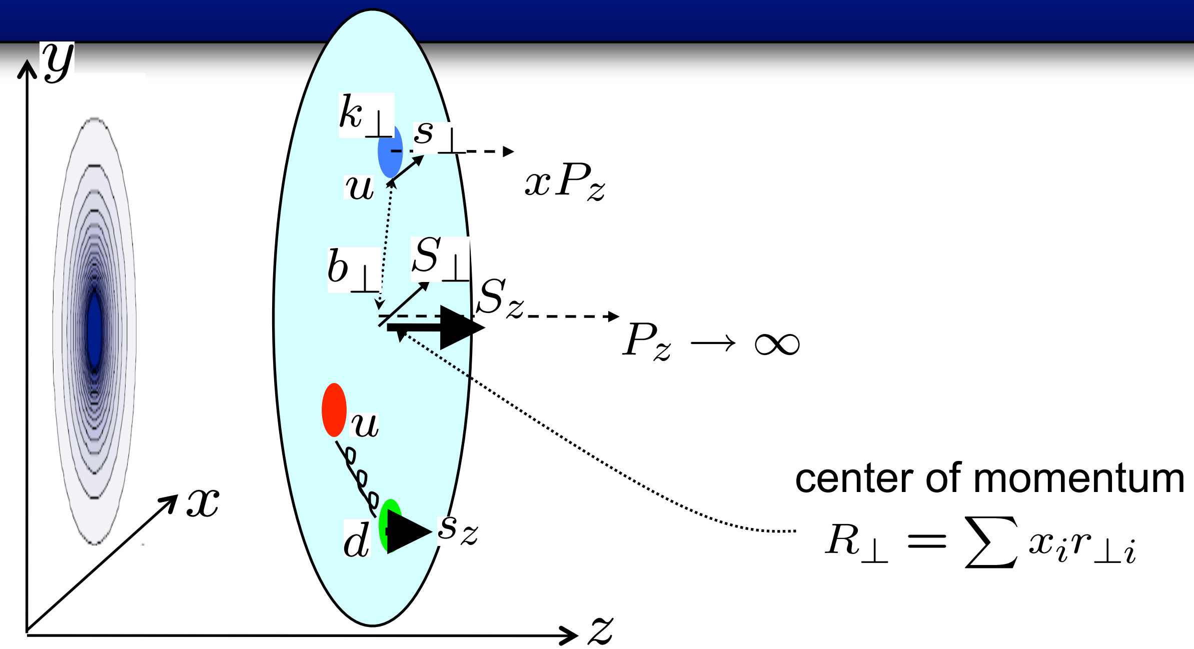
$$H(x,\xi,t), \widetilde{H}, E, \widetilde{E}$$
$$H(x,0,0) = q(x)$$
$$\widetilde{H}(x,0,0) = \Delta q(x)$$
$$\int H(x,\xi,t)dx = F(t)$$





$$J^q(Q^2) = \frac{1}{2}\sum_{i=q,\bar{q}}\int_{-1}^{1} x(H^i(Q^2,x,\xi,0) + E^i(Q^2,x,\xi,0))dx$$
$$J^G(Q^2) = \frac{1}{2}\int_{-1}^{1} x(H^G(Q^2,x,\xi,0) + E^G(Q^2,x,\xi,0))dx$$

Ji's sum rule

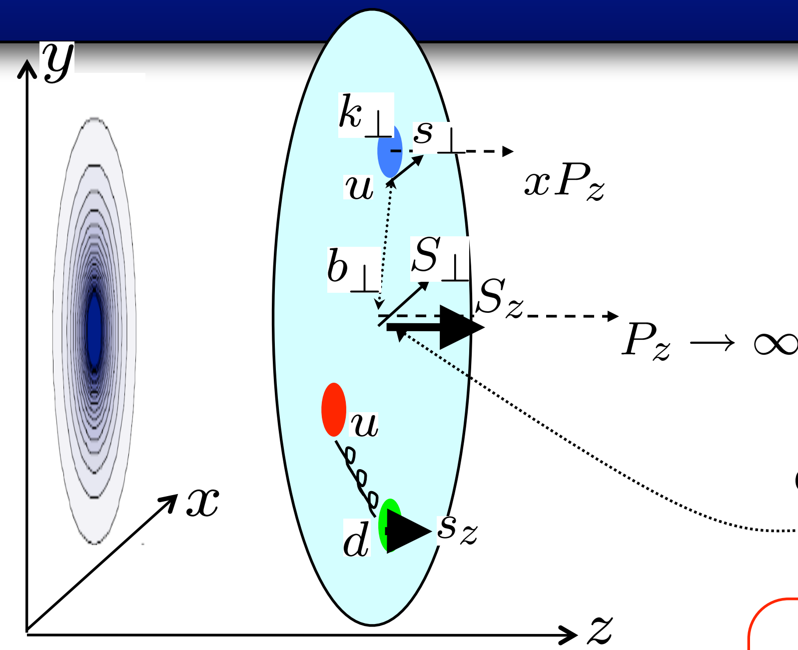


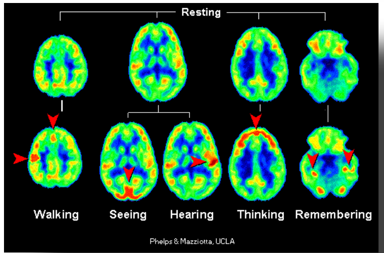
$$\mathcal{H}(x, \vec{b}_\perp) = \int \frac{d^2\Delta_\perp}{2\pi} e^{i\vec{\Delta}_\perp . \vec{b}_\perp} H(x, 0, -\vec{\Delta}_\perp^2).$$

$$\tilde{\mathcal{H}}(x, \vec{b}_\perp) = \int \frac{d^2\Delta_\perp}{2\pi} e^{i\vec{\Delta}_\perp . \vec{b}_\perp} \tilde{H}(x, 0, -\vec{\Delta}_\perp^2),$$

$$\mathcal{E}(x, \vec{b}_\perp) = \int \frac{d^2\Delta_\perp}{2\pi} e^{i\vec{\Delta}_\perp . \vec{b}_\perp} E(x, 0, -\vec{\Delta}_\perp^2).$$

3-Dimensional image of nucleon in the mixed transverse plane-longitudinal momentum space





center of momentum

$$R_\perp = \sum x_i r_{\perp i}$$

$$\mathcal{H}(x, \vec{b}_\perp) = \int \frac{d^2\Delta_\perp}{2\pi} e^{i\vec{\Delta}_\perp . \vec{b}_\perp} H(x, 0, -\vec{\Delta}_\perp^2).$$

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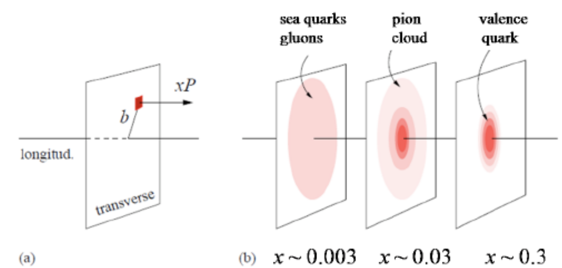
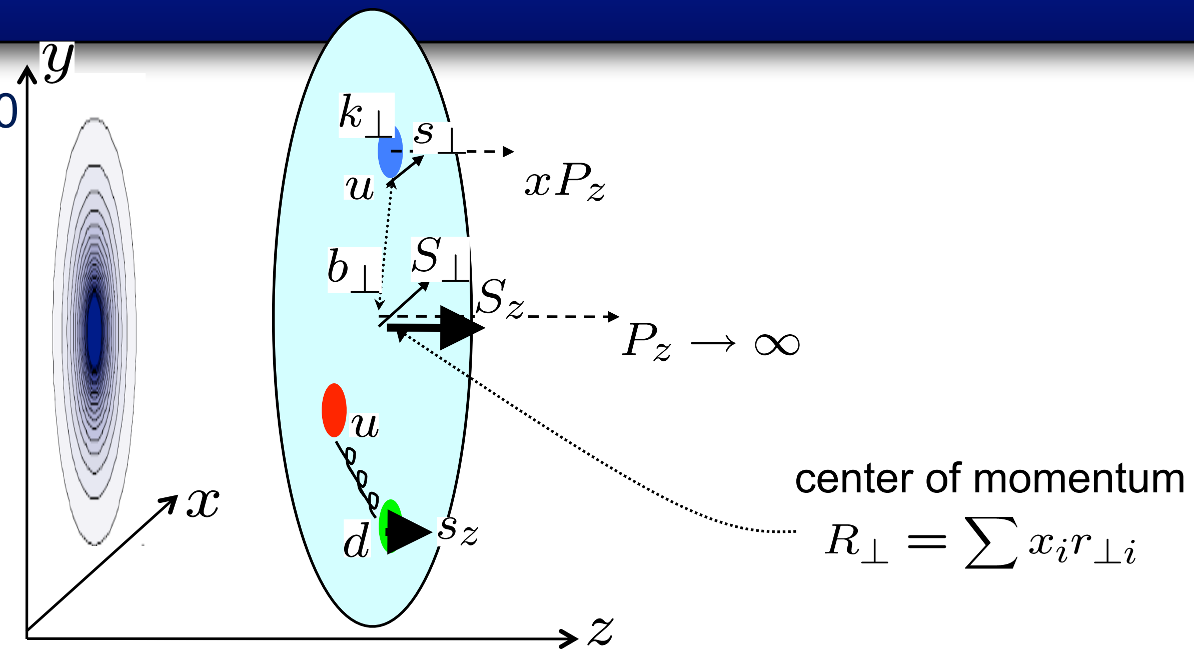
„Tomography”



3-Dimensional image of nucleon in the mixed transverse plane-longitudinal momentum space

Spatial deformation & GPD

Burhardt,2000

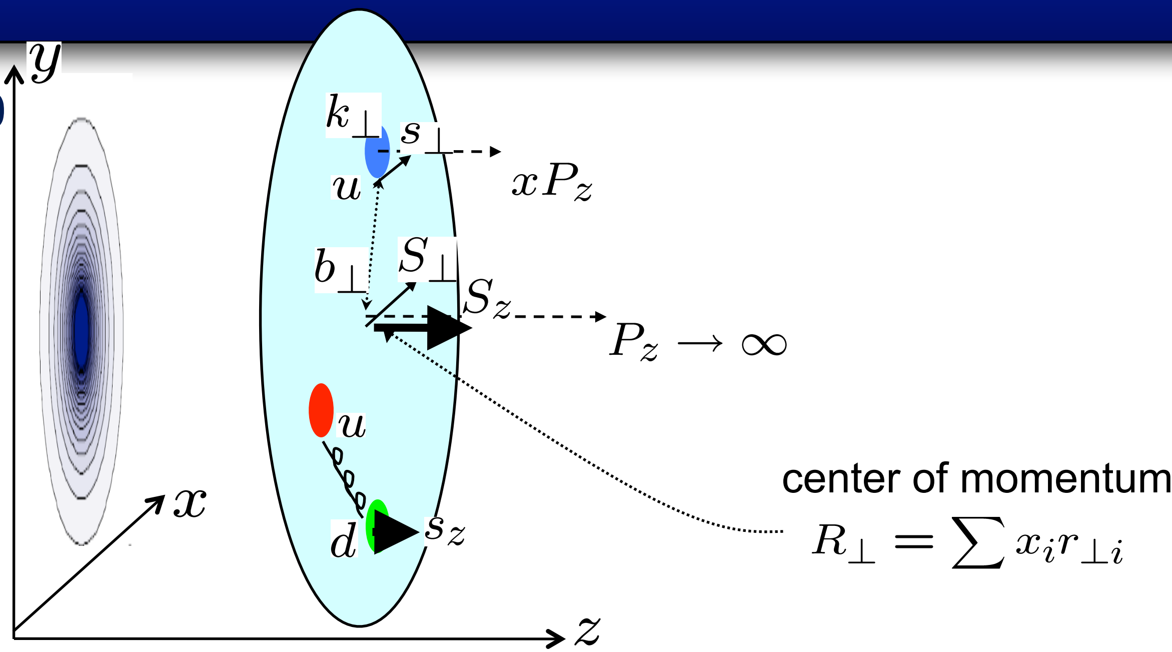


For a transversely polarized nucleon (e.g. polarized in the $+\hat{x}$-direction) the IPD $q_{\hat{x}}(x, \vec{b}_\perp)$ is no longer symmetric due to the non-zero value of the spin-flip GPD E. This deformation is described by the gradient of the Fourier transform of E:

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

non-zero spin-flip GPD E - existence of non-zero orbital momentum

Burhardt,2000



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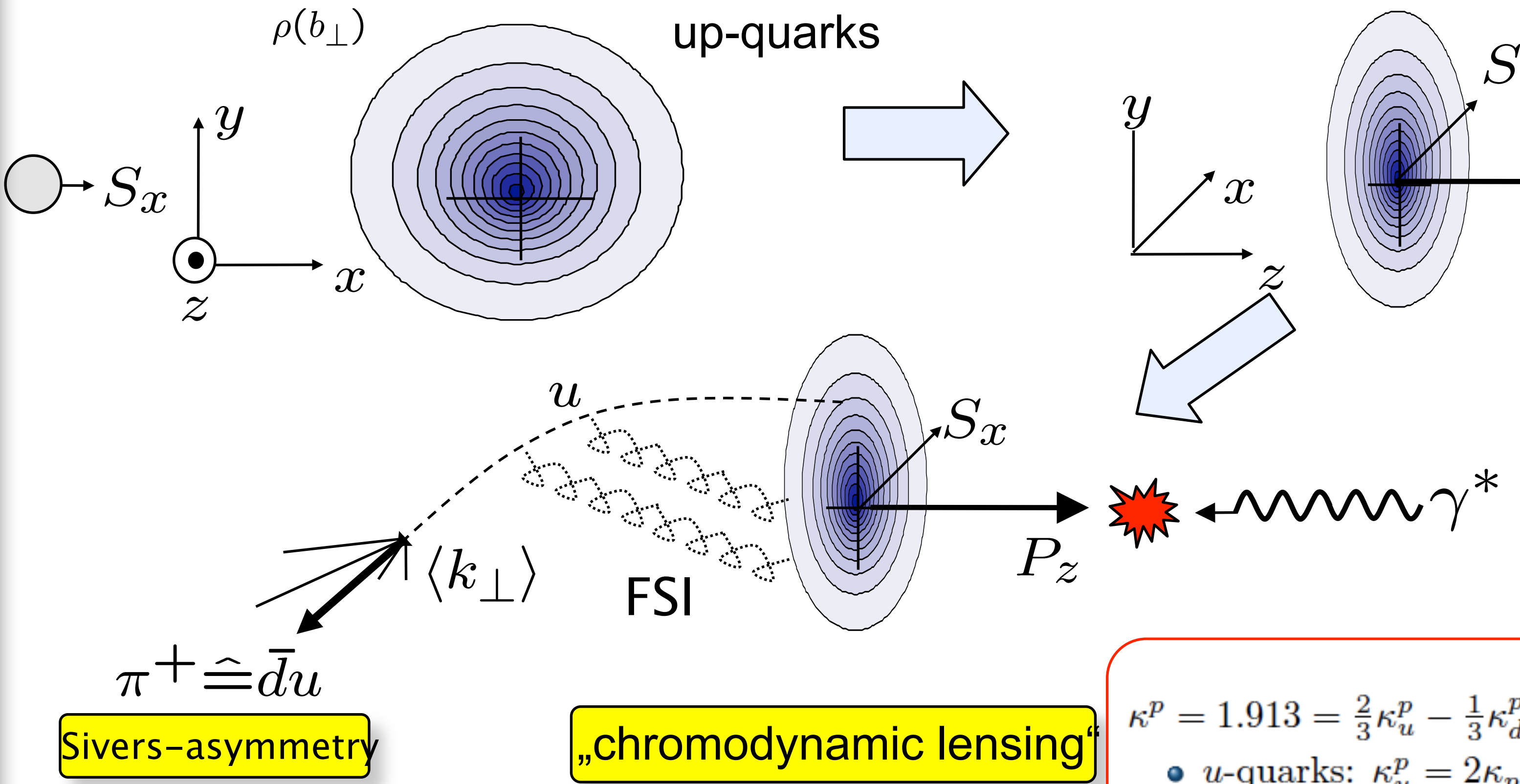
non-zero spin-flip GPD E - existence of non-zero orbital momentum

Sivers function and spatial deformation

M.Burhardt 2002/2003

Dynamical origin of quark transverse momentum



$\kappa^p = 1.913 = \frac{2}{3}\kappa_u^p - \frac{1}{3}\kappa_d^p + ...$

- u-quarks: $\kappa_u^p = 2\kappa_p + \kappa_n = 1.673$

↪ shift in $+\hat{y}$ direction

- d-quarks: $\kappa_d^p = 2\kappa_n + \kappa_p = -2.033$

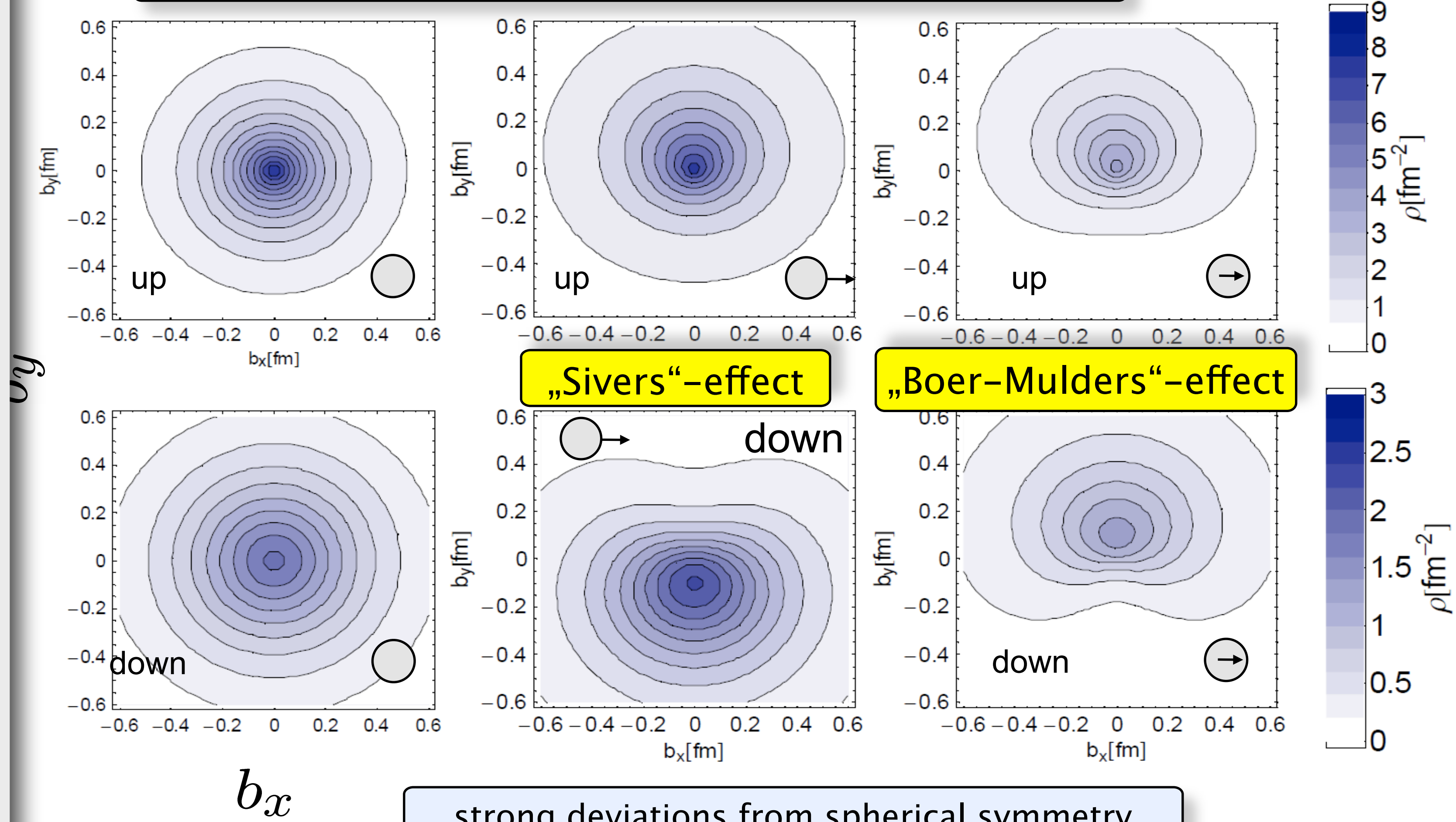
↪ shift in $-\hat{y}$ direction

- $\langle b_y^q \rangle = \mathcal{O}(\pm 0.2 fm)$!!!!

Deformation details are model-dependent but the size and directions is determined by anomalous magnetic moments of proton and neutron.

Lowest x-moments of quark densities in coordinate space

QCDSF $n_f=2$ Clover, Phys.Rev.Lett. 2007 [hep-lat/0612032]



strong deviations from spherical symmetry

Lowest x-moments of quark densities in coordinate space

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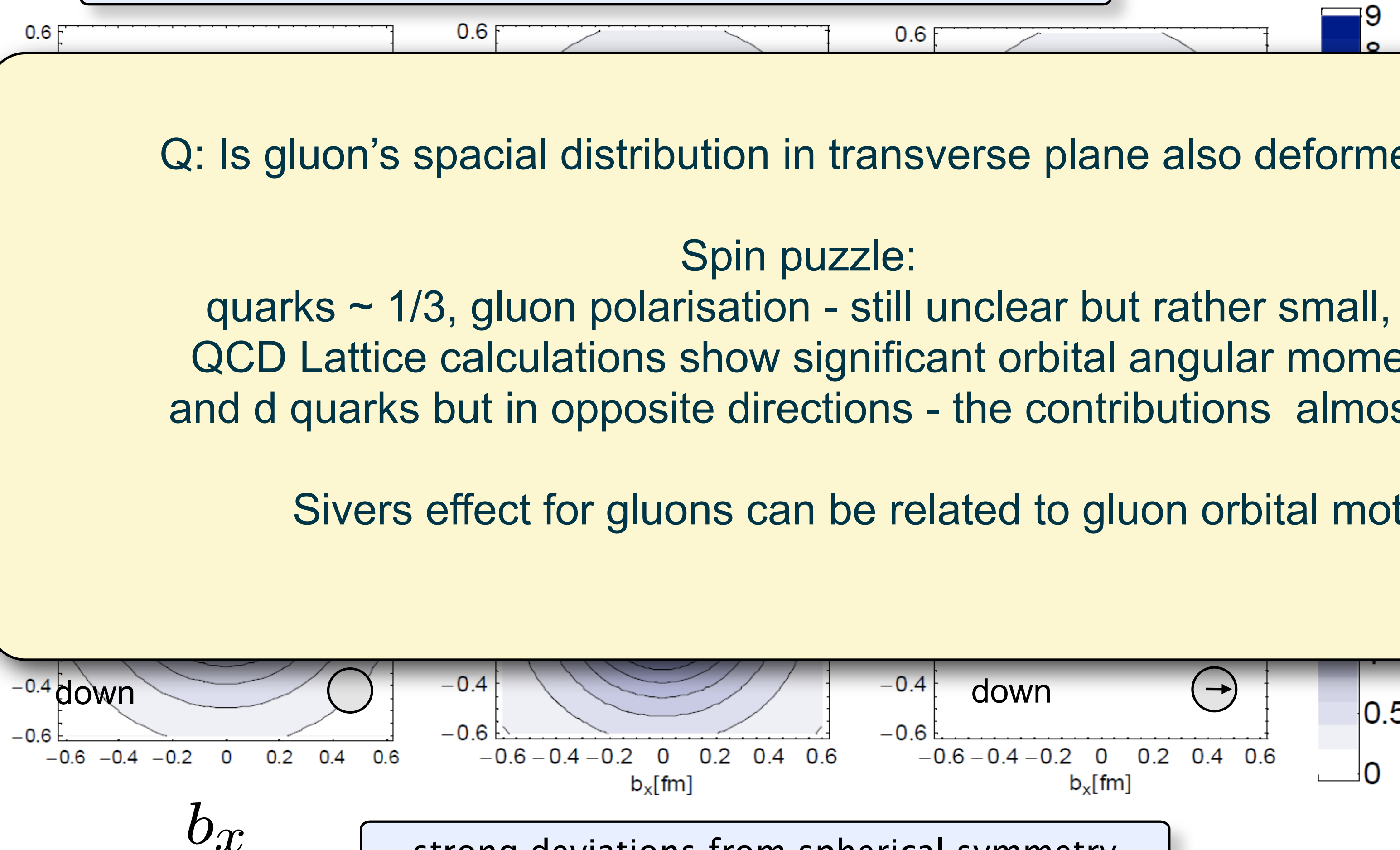


Q: Is gluon's spacial distribution in transverse plane also deformed?

Spin puzzle:
quarks ~ 1/3, gluon polarisation - still unclear but rather small,
QCD Lattice calculations show significant orbital angular momenta of u and d quarks but in opposite directions - the contributions almost cancel.

Sivers effect for gluons can be related to gluon orbital motion

strong deviations from spherical symmetry

Sivers for gluons @ COMPASS

The idea: selection of high-p_T hadron pairs to increase photon-gluon fusion (PGF) similar to Δg determination with longitudinally polarised target.

difficulties comparing to Δg
- asymmetry in azimuthal angle
- gluon „simulated" from pair of hadrons from PGF
- Sivers effect due to final interactions (no analyzing powers)

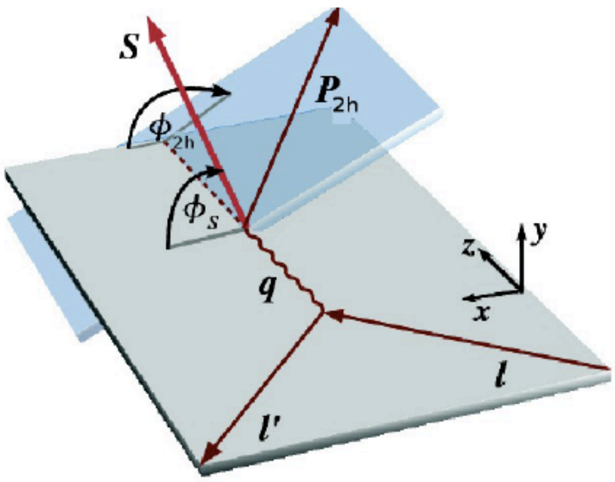
$$P_{2h} = p_1 + p_2$$
$$R = \frac{1}{2}(p_1 - p_2)$$

Single-spin asymmetry is measured:

$$A_T^h \sim \frac{d^6\sigma^{\uparrow} - d^6\sigma^{\downarrow}}{d^6\sigma^{\uparrow} + d^6\sigma^{\downarrow}}.$$

8 asymmetries; concentrated on Sivers

σ- two-hadron cross-section integrated over ϕ_R;
Phys.Rev.Lett.113, 062003 (2014), Phys. Rev. D 90, 074006 (2014)



The statistically weighted method was used, similar to open-charm and all-p_T methods used in Δg determination
J.Pretz, J-M Le Goff NIM A 602 (2009) 594
COMPASS open-charm: Phys. Rev. D (2013) 052018

$P_{2h} = p_1 + p_2$
Sivers angle:
$\phi = \phi_{2h} - \phi_S$

The weighted method

The number of events:

$$n_c(\vec{x}) = \alpha_c(\vec{x})(1 + \beta_c(\vec{x})A_{UT}^{\sin(\phi_{2h}-\phi_s)}(\vec{x}))$$

Every event is weighted by the weight ω

$$p_c := \int \omega(\vec{x}) n_c(\vec{x}) d\vec{x} = \int \omega(\vec{x})\alpha_c(\vec{x}) d\vec{x}$$

$$+ \int \omega(\vec{x})\alpha_c(\vec{x})\beta_c(\vec{x})A_{UT}^{\sin(\phi_{2h}-\phi_s)}(\vec{x}) d\vec{x} \approx \sum_{i=1}^{N_c} \omega_i,$$

$$\sum_{i=1}^{N_c} \omega_i = \tilde{\alpha}_c(1 + \{\beta_c\}_\omega \{A_{UT}^{\sin(\phi_{2h}-\phi_s)}\}_{\omega\beta_c}),$$

where

$$\tilde{\alpha}_c = \int \omega(\vec{x})\alpha_c(\vec{x}) d\vec{x},$$

$$\{A_{UT}^{\sin(\phi_{2h}-\phi_s)}\}_{\omega\beta_c} = \frac{\int A_{UT}^{\sin(\phi_{2h}-\phi_s)}(\vec{x})\omega(\vec{x})\beta_c\alpha_c(\vec{x}) d\vec{x}}{\int \omega(\vec{x})\beta_c\alpha_c(\vec{x}) d\vec{x}},$$

$$\{\beta\}_\omega = \frac{\int \beta(\vec{x})\omega(\vec{x})\alpha_c(\vec{x}) d\vec{x}}{\int \omega(\vec{x})\alpha_c(\vec{x}) d\vec{x}} \approx \frac{\sum_i \beta_i \omega_i}{\sum_i \omega_i}.$$

where:

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

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

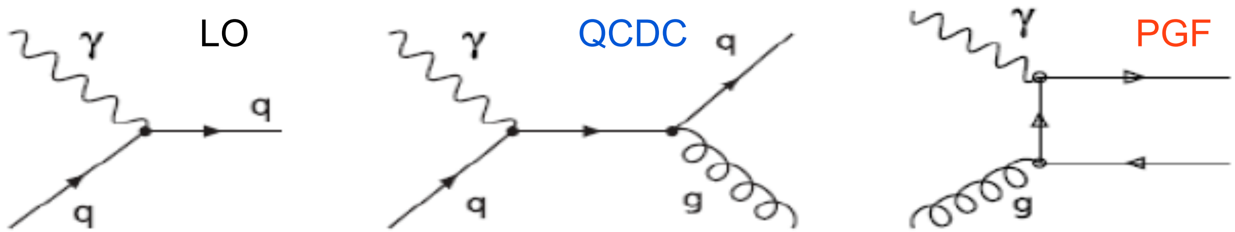
$$\beta_c(\vec{x}) = P_T f \sin(\phi_{2h} - \phi_s)$$

c= u, d, u', d'

$$\omega(\vec{x}) = \frac{\beta(\vec{x})}{P_T} = f \sin(\phi_{2h} - \phi_s)$$

The weighted method

Physical model: three basic processes @LO



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

$$\begin{aligned}
\omega_{PGF} &\equiv \omega^G = R_{PGF} f \sin(\phi_{2h} - \phi_s) = \frac{\beta^G}{P_T}, \\
\omega_{LP} &\equiv \omega^L = R_{LP} f \sin(\phi_{2h} - \phi_s) = \frac{\beta^L}{P_T}, \\
\omega_{QCDC} &\equiv \omega^C = R_{QCDC} f \sin(\phi_{2h} - \phi_s) = \frac{\beta^C}{P_T}.
\end{aligned}$$

The weighted method

Physical model: three basic processes @LO

leads to 12 eqs.:

$$p_c^j = \sum_{i=1}^{N_c} \omega_i^j = \tilde{\alpha}_c^j (1 + \{\beta_c^G\}_{\omega^j} A_{PGF}^{\sin(\phi_{2h}-\phi_s)}(\langle x_G \rangle)$$
$$+ \{\beta_c^L\}_{\omega^j} A_{LP}^{\sin(\phi_{2h}-\phi_s)}(\langle x_{Bj} \rangle) + \{\beta_c^C\}_{\omega^j} A_{QCDC}^{\sin(\phi_{2h}-\phi_s)}(\langle x_C \rangle))$$
$$= \tilde{\alpha}_c^j \left(1 + A_{PGF}\{\beta^G\}_{\omega^j} + A_{LP}\{\beta^L\}_{\omega^j} + A_{QCDC}\{\beta^C\}_{\omega^j}\right)$$

with 15 unknows: (3 asymmeries + 12 acceptances) but thanks to $\frac{\tilde{\alpha}_u^j \tilde{\alpha}_{d'}^j}{\tilde{\alpha}_d^j \tilde{\alpha}_{u'}^j} = 1,$ it is reduced to 12. *Here j stands for LO, QCDC and PGF, respectively

To determine asymmetries the minimalizatiion procedure has been used:

$$\chi^2 = (\vec{N_{exp}} - \vec{N_{obs}})^T Cov^{-1} (\vec{N_{exp}} - \vec{N_{obs}})$$

$\sim \sum_{N_c} \omega_x \omega_y.$

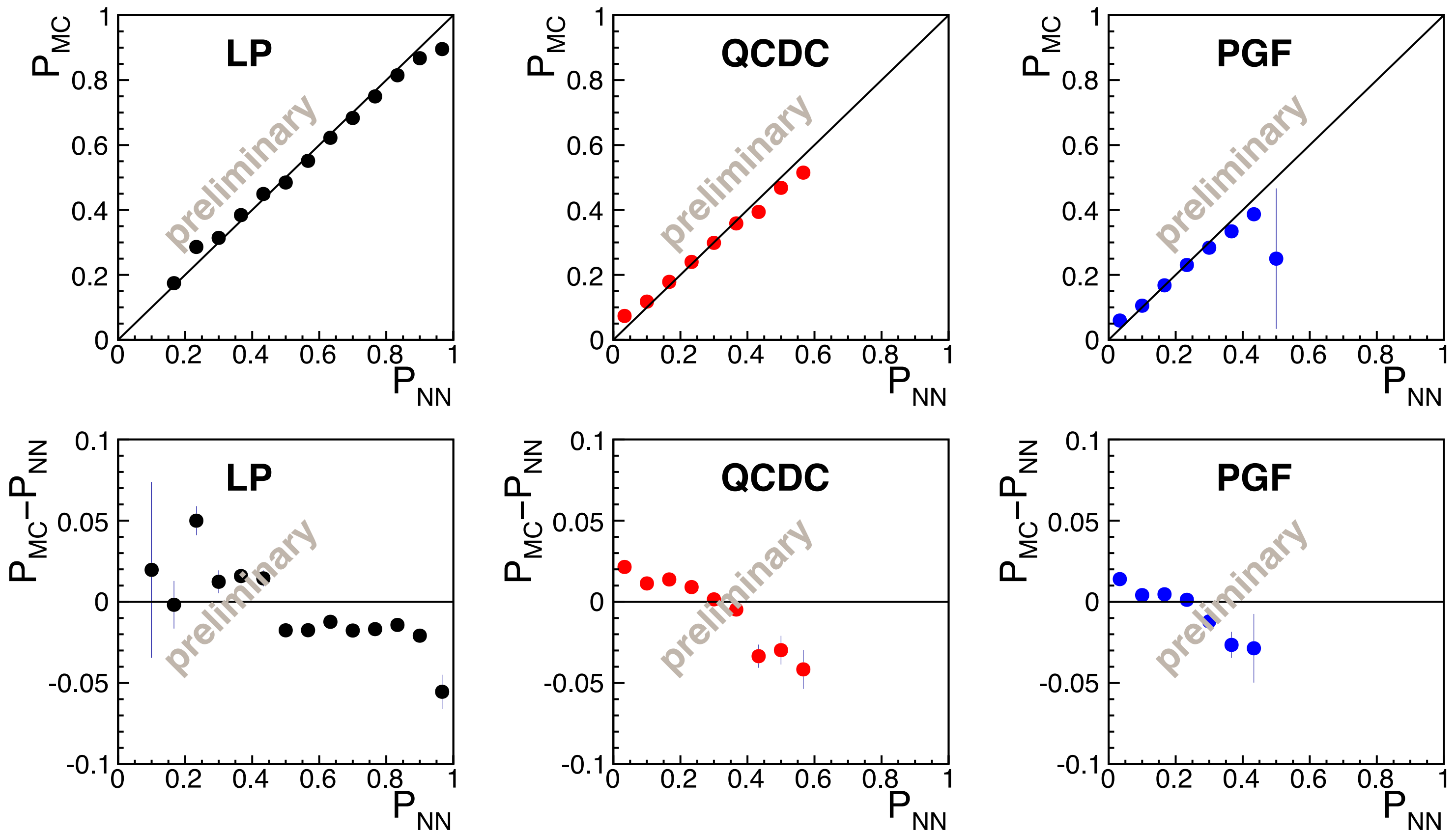
$$\vec{N_{obs}} = (\sum_{i=0}^{N_u} \omega_i^G, \ldots, \sum_{i=0}^{N_{d'}} \omega_i^C),$$

$$\vec{N_{exp}} = (N_{exp,G}^u, \ldots, N_{exp,C}^{d'}), \qquad N_{exp,j}^c = \tilde{\alpha}_c^j \left(1 + A_{PGF}\{\beta^G\}_{\omega^j} + A_{LP}\{\beta^L\}_{\omega^j} + A_{QCDC}\{\beta^C\}_{\omega^j}\right)$$

Artificial Neural Network approach - validation

To find R's (fractions or probabilities of three processes) the ANN approach has been used (as in longitudinal high-p_T analysis for gluon polarisation measurement, see: Phys. Lett. B 718 (2013) 922)

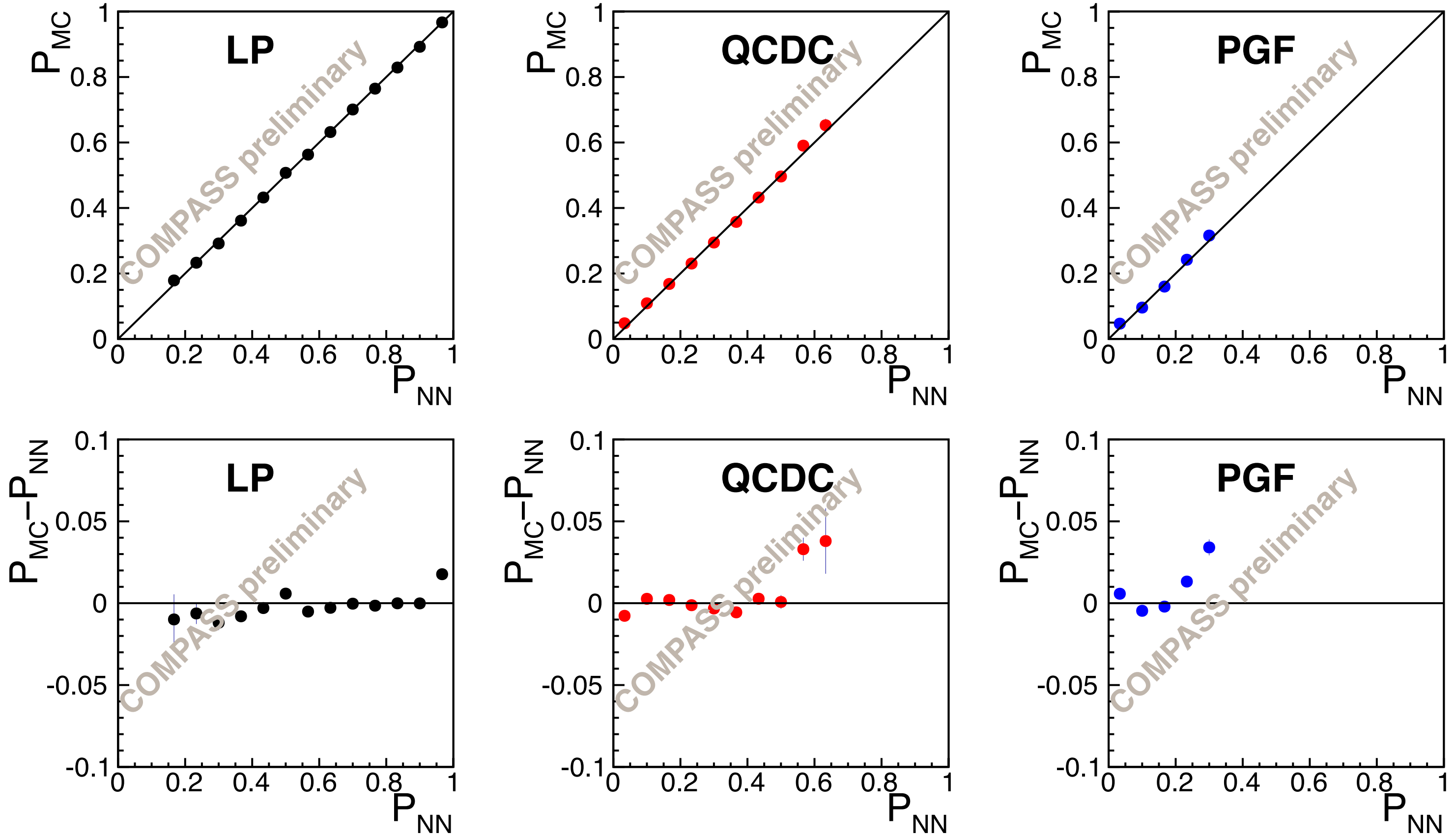
deuteron target



training vector: p_T, p_L, x_{Bjk}, Q^2

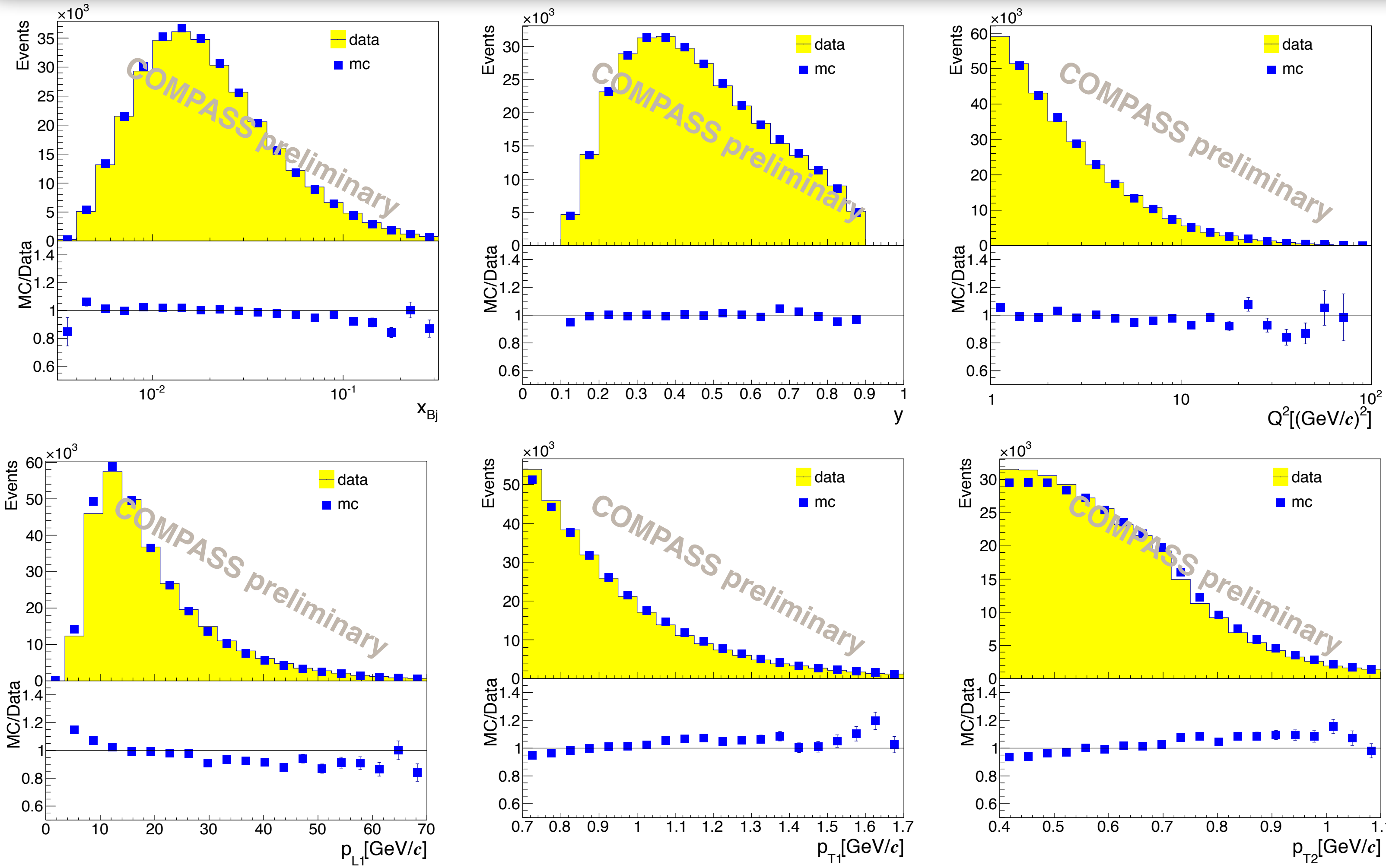
To find R's (fractions or probabilities of three processes) the ANN approach has been used (as in longitudinal high-p_T analysis for gluon polarisation measurement, see: Phys. Lett. B 718 (2013) 922)

proton target



training vector: p_T, p_L, x_{Bjk}, Q^2

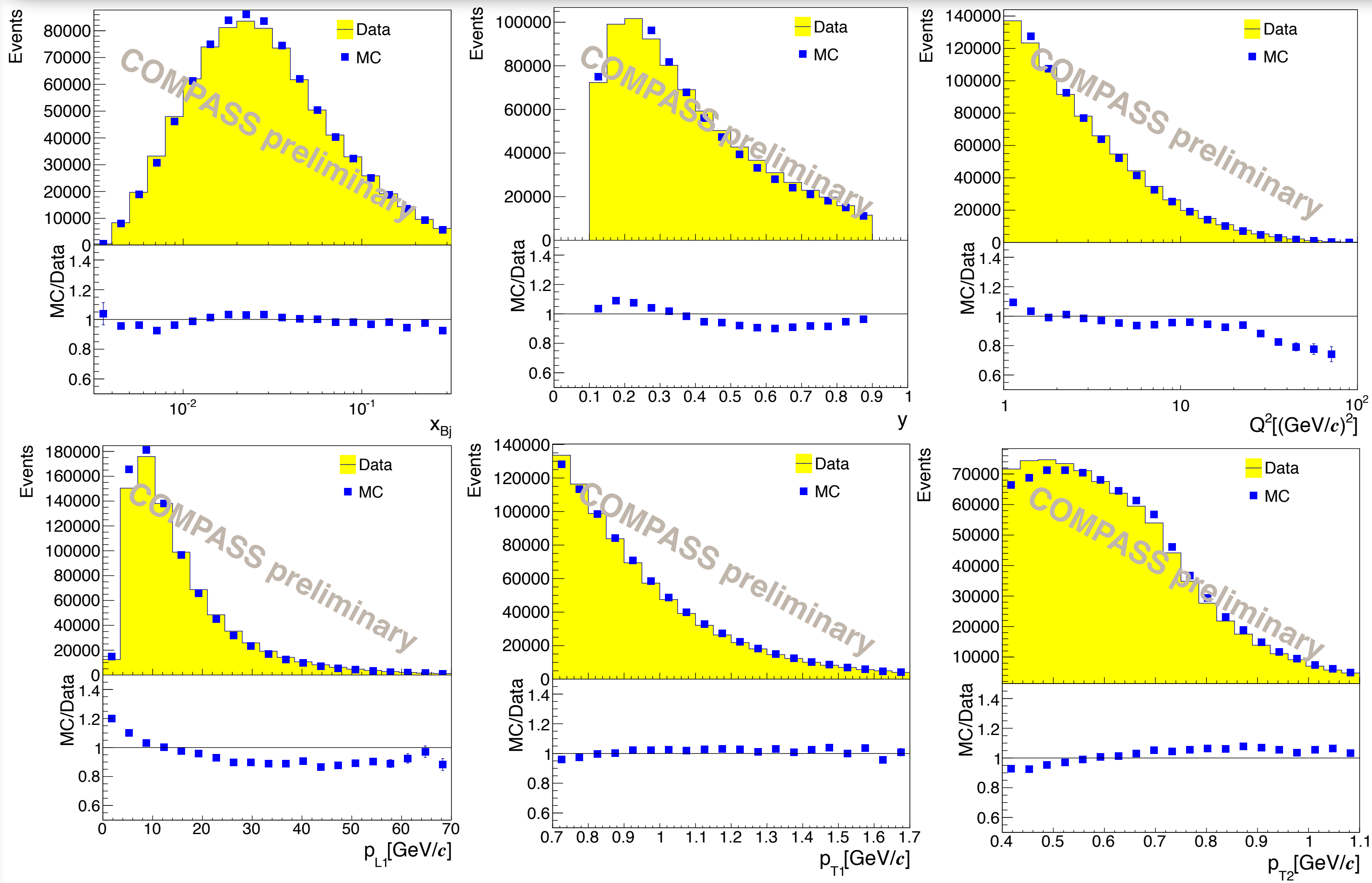
Data-MC comparison



good agreement (COMPASS tuning high-p_T)

deuteron target

Data-MC comparison



good agreement (COMPASS tuning high-p_T)

proton target

Validation of the method

deuteron target

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

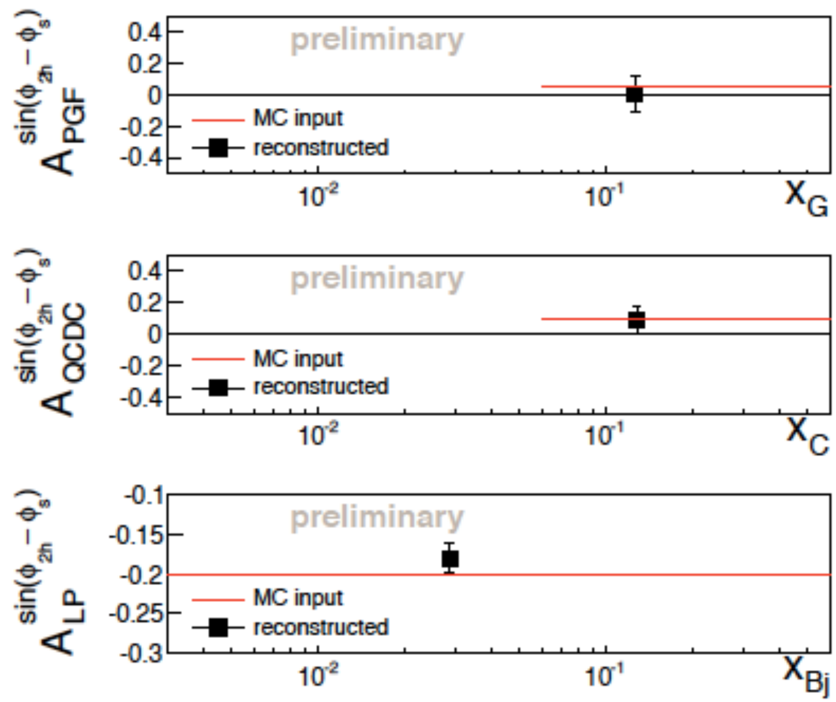
  ϕ_{2h} - azimuthal angle of the vector sum of the 2 leading hadron momenta.

A - assumed asymmetry for LO, QCDC and PGF

- For each MC event we get

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

Sivers Asymmetry



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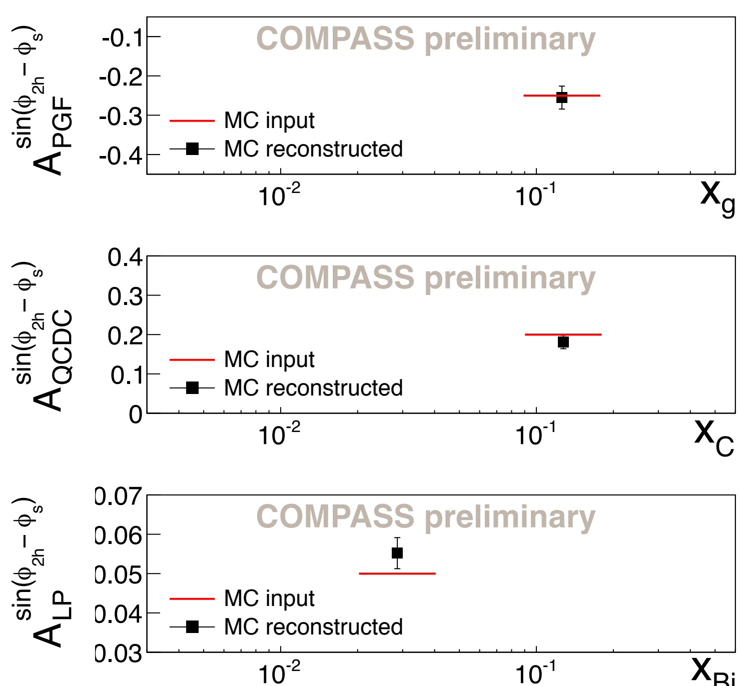
proton target



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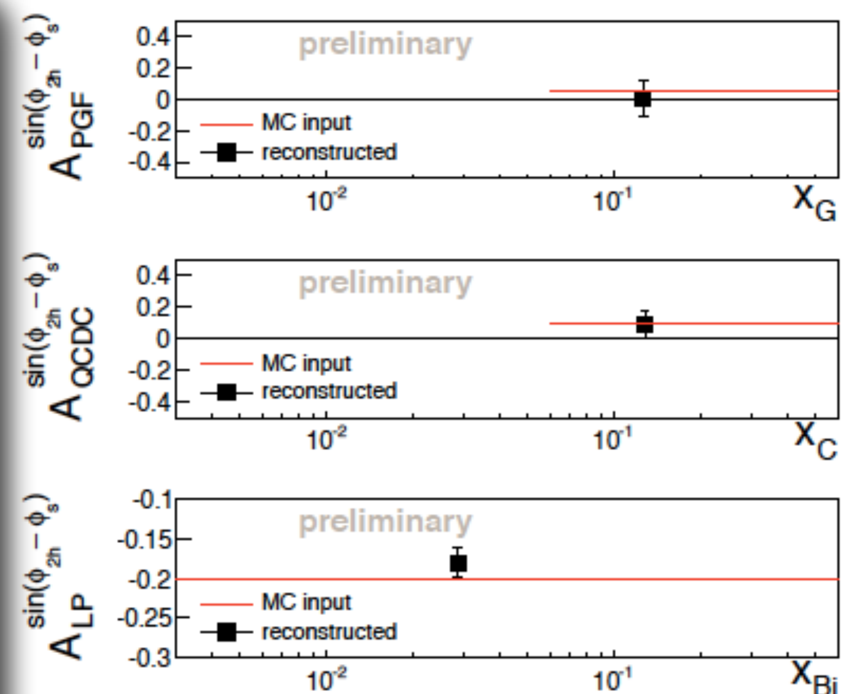
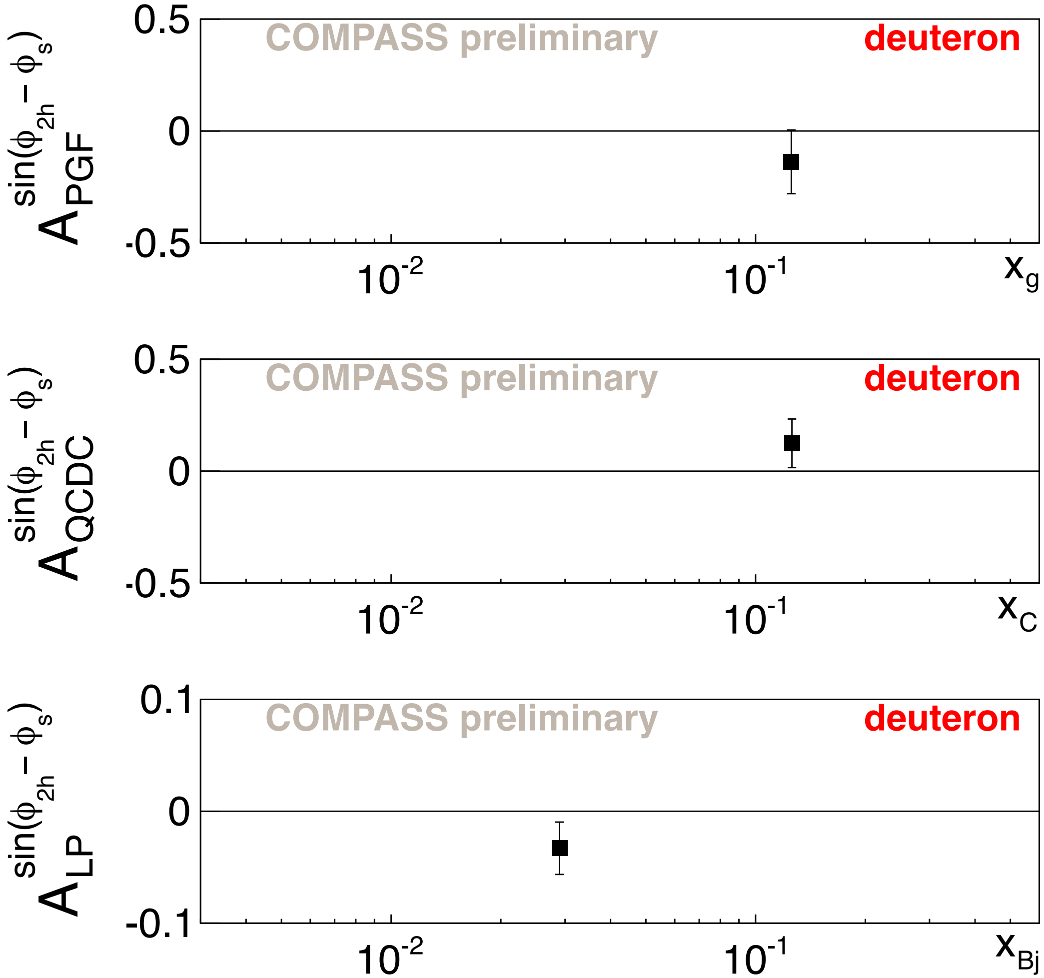


Data selection & preliminary results

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

$z_1 + z_2 < 0.9$



$$A_{PGF}^{\sin(\phi_{2h}-\phi_s)} = -0.14 \pm 0.15(stat.) \pm 0.06(syst.) \text{ at } \langle x_G \rangle = 0.13$$

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  - $Q^2 > 1 (GeV/c)^2$
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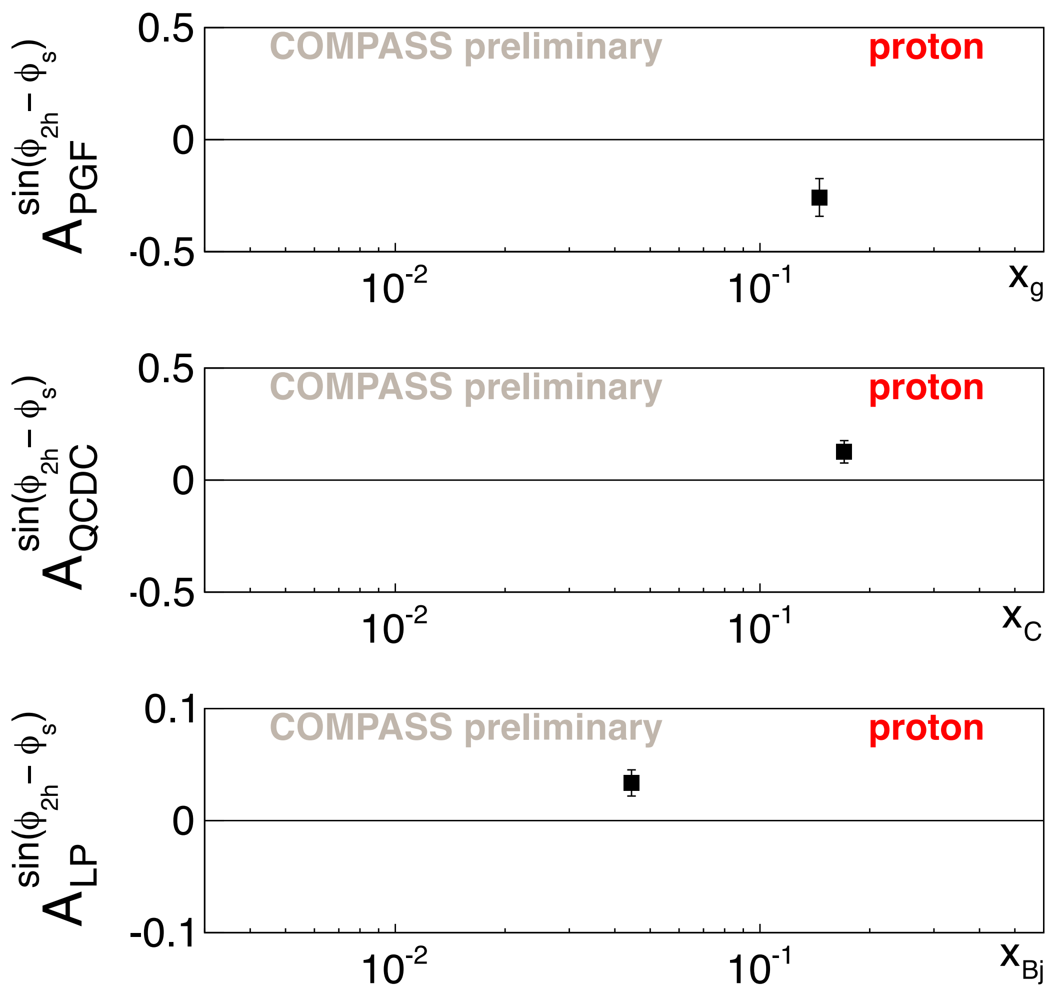
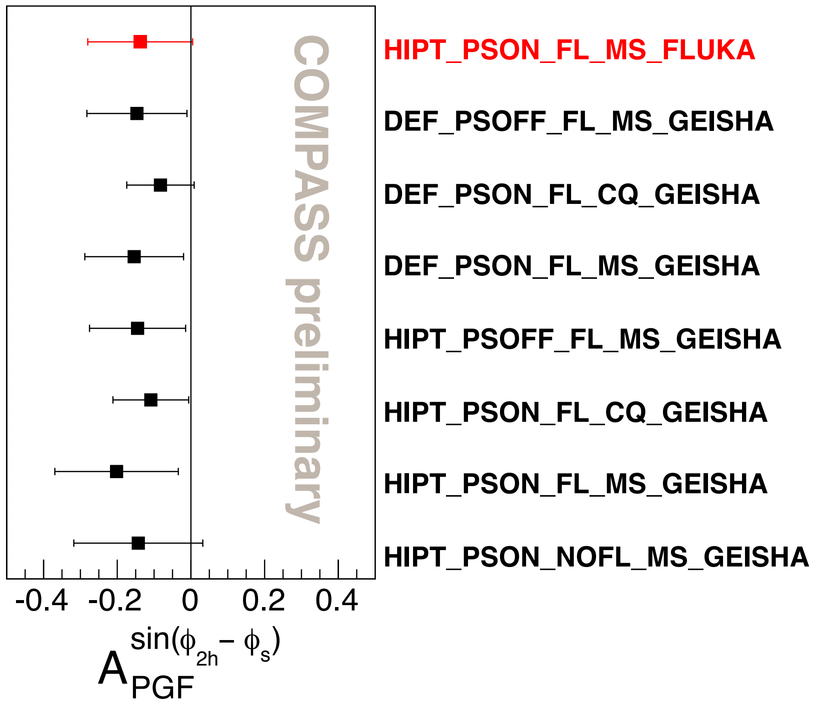
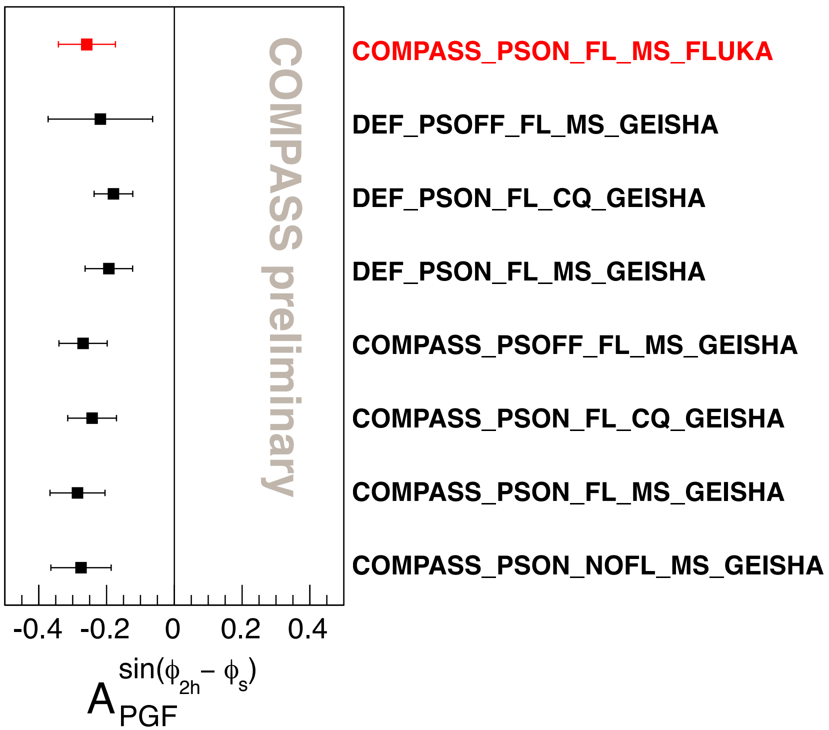


$$A_{PGF}^{\sin(\phi_{2h}-\phi_s)} = -0.26 \pm 0.09(stat.) \pm 0.08(syst.) \text{ at } \langle x_G \rangle = 0.15$$

deuteron target



proton target



Summary

- For the first time preliminary result for Sivers asymmetry for gluons has been obtained from COMPASS on deuteron and on proton targets data:

$$A_{PGF}^{\sin(\phi_{2h}-\phi_s)} = -0.14 \pm 0.15(stat.) \pm 0.06(syst.) \text{ at } \langle x_G \rangle = 0.13$$

$$A_{PGF}^{\sin(\phi_{2h}-\phi_s)} = -0.26 \pm 0.09(stat.) \pm 0.08(syst.) \text{ at } \langle x_G \rangle = 0.15$$

- The result on deuteron is compatible with zero but the central value is negative with large error
- Proton data show a value which is negative, 3σ below zero and statistically compatible with deuteron result

S.J.Brodsky & S. Gardner,Phys.Lett. B643 (2006) 22-28

Thank you for your attention

Gluon Contribution to the Sivers Effect
COMPASS Results on Deuteron Target

Adam Szabelski
Krzysztof Kurek

National Centre for
Nuclear Research
Warsaw, Poland

XVI Workshop on High Energy Spin Physics
DSPIN-15
Dubna, Russia, September 8-12

Backup slides

SIDIS cross section decomposition LO

$$\frac{d\sigma}{xdyd\phi_S d\phi_h dz_h dP_{hT}^2} = \frac{e^4}{32\pi^2 x Q^2}\frac{y}{1-\varepsilon}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon\ F_{UU,L} + \varepsilon\ cos(2\phi_h)F_{UU}^{cos2\phi_h}$$
$$+\sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_h F_{UU}^{cos\phi_h} + h_l sin\phi_h F_{LU}^{sin\phi_h}\right)$$
$$+S_{\parallel}\left[\sqrt{2\varepsilon(1+\varepsilon)}sin\phi_h F_{UL}^{sin\phi_h} + \varepsilon\ sin(2\phi_h)F_{UL}^{sin2\phi_h}\right]$$
$$+S_{\parallel}h_l\left[\sqrt{1-\varepsilon^2}F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}cos\phi_h F_{LL}^{cos\phi_h}\right]$$
$$+|S_{\perp}|\Big[sin(\phi_h-\phi_S)\left(F_{UT,T}^{sin(\phi_h-\phi_S)} + \varepsilon\ F_{UT,L}^{sin(\phi_h-\phi_S)}\right)$$
$$+\varepsilon\ sin(3\phi_h-\phi_S)F_{UT}^{sin(3\phi_h-\phi_S)} + \varepsilon\ sin(\phi_h+\phi_S)F_{UT}^{sin(\phi_h+\phi_S)}$$
$$+\sqrt{2\varepsilon(1+\varepsilon)}\left(sin\phi_S F_{UT}^{sin\phi_S} + sin(2\phi_h-\phi_S)F_{UT}^{sin(2\phi_h-\phi_S)}\right)\Big]$$
$$+|S_{\perp}|h_l\Big[\sqrt{1-\varepsilon^2}cos(\phi_h-\phi_S)F_{LT}^{cos(\phi_h-\phi_S)}$$
$$+\sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_S F_{LT}^{cos\phi_S} + cos(2\phi_h-\phi_S)F_{LT}^{cos(2\phi_h-\phi_S)}\right)\Big]\Big\},$$

A catalog of PDFs

SIDIS cross section decomposition LO

$$\frac{d\sigma}{xdyd\phi_S d\phi_h dz_h dP_{hT}^2} = \frac{e^4}{32\pi^2 x Q^2}\frac{y}{1-\varepsilon}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon\, F_{UU,L} + \varepsilon\, cos(2\phi_h) F_{UU}^{cos2\phi_h}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_h F_{UU}^{cos\phi_h} + h_l sin\phi_h F_{LU}^{sin\phi_h}\right)$$
$$+ S_{\|}\left[\sqrt{2\varepsilon(1+\varepsilon)} sin\phi_h F_{UL}^{sin\phi_h} + \varepsilon\, sin(2\phi_h) F_{UL}^{sin2\phi_h}\right]$$
$$+ S_{\|} h_l \left[\sqrt{1-\varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)} cos\phi_h F_{LL}^{cos\phi_h}\right]$$
$$+ |S_\perp|\Big[sin(\phi_h - \phi_S)\left(F_{UT,T}^{sin(\phi_h-\phi_S)} + \varepsilon\, F_{UT,L}^{sin(\phi_h-\phi_S)}\right)$$
$$+ \varepsilon\, sin(3\phi_h - \phi_S) F_{UT}^{sin(3\phi_h-\phi_S)} + \varepsilon\, sin(\phi_h+\phi_S) F_{UT}^{sin(\phi_h+\phi_S)}$$
$$+ \sqrt{2\varepsilon(1+\varepsilon)}\left(sin\phi_S F_{UT}^{sin\phi_S} + sin(2\phi_h-\phi_S) F_{UT}^{sin(2\phi_h-\phi_S)}\right)\Big]$$
$$+ |S_\perp| h_l \Big[\sqrt{1-\varepsilon^2} cos(\phi_h-\phi_S) F_{LT}^{cos(\phi_h-\phi_S)}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_S F_{LT}^{cos\phi_S} + cos(2\phi_h-\phi_S) F_{LT}^{cos(2\phi_h-\phi_S)}\right)\Big]\Big\},$$

Cahn & Boer-Mulders

unpolarised target

Spares

Spares

SIDIS cross section decomposition LO

$$\frac{d\sigma}{xdyd d\phi_S d\phi_h dz_h dP_{hT}^2} = \frac{e^4}{32\pi^2 x Q^2}\frac{y}{1-\varepsilon}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon\, F_{UU,L} + \varepsilon\, cos(2\phi_h) F_{UU}^{cos2\phi_h}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_h F_{UU}^{cos\phi_h} + h_l sin\phi_h F_{LU}^{sin\phi_h}\right)$$
$$+ S_{\parallel}\left[\sqrt{2\varepsilon(1+\varepsilon)} sin\phi_h F_{UL}^{sin\phi_h} + \varepsilon\, sin(2\phi_h) F_{UL}^{sin2\phi_h}\right]$$
$$+ S_{\parallel} h_l\left[\sqrt{1-\varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)} cos\phi_h F_{LL}^{cos\phi_h}\right]$$
$$+ |S_\perp|\Big[sin(\phi_h-\phi_S)\left(F_{UT,T}^{sin(\phi_h-\phi_S)} + \varepsilon\, F_{UT,L}^{sin(\phi_h-\phi_S)}\right)$$
$$+ \varepsilon\, sin(3\phi_h-\phi_S) F_{UT}^{sin(3\phi_h-\phi_S)} + \varepsilon\, sin(\phi_h+\phi_S) F_{UT}^{sin(\phi_h+\phi_S)}$$
$$+ \sqrt{2\varepsilon(1+\varepsilon)}\left(sin\phi_S F_{UT}^{sin\phi_S} + sin(2\phi_h-\phi_S) F_{UT}^{sin(2\phi_h-\phi_S)}\right)\Big]$$
$$+ |S_\perp| h_l\Big[\sqrt{1-\varepsilon^2} cos(\phi_h-\phi_S) F_{LT}^{cos(\phi_h-\phi_S)}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_S F_{LT}^{cos\phi_S} + cos(2\phi_h-\phi_S) F_{LT}^{cos(2\phi_h-\phi_S)}\right)\Big]\Big\},$$

Cahn & Boer-Mulders

unpolarised target

longitudinaly polarised target

A catalog of PDFs

SIDIS cross section decomposition LO

$$\frac{d\sigma}{x dy d\phi_S d\phi_h dz_h dP_{hT}^2} = \frac{e^4}{32\pi^2 x Q^2}\frac{y}{1-\varepsilon}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon\, F_{UU,L} + \varepsilon\, cos(2\phi_h) F_{UU}^{cos 2\phi_h}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_h F_{UU}^{cos\phi_h} + h_l sin\phi_h F_{LU}^{sin\phi_h}\right)$$
$$+ S_\parallel \left[\sqrt{2\varepsilon(1+\varepsilon)} sin\phi_h F_{UL}^{sin\phi_h} + \varepsilon\, sin(2\phi_h) F_{UL}^{sin 2\phi_h}\right]$$
$$+ S_\parallel h_l \left[\sqrt{1-\varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)} cos\phi_h F_{LL}^{cos\phi_h}\right]$$
$$+ |S_\perp| \Big[sin(\phi_h - \phi_S)\left(F_{UT,T}^{sin(\phi_h-\phi_S)} + \varepsilon\, F_{UT,L}^{sin(\phi_h-\phi_S)}\right)$$
$$+ \varepsilon\, sin(3\phi_h - \phi_S) F_{UT}^{sin(3\phi_h-\phi_S)} + \varepsilon\, sin(\phi_h + \phi_S) F_{UT}^{sin(\phi_h+\phi_S)}$$
$$+ \sqrt{2\varepsilon(1+\varepsilon)}\left(sin\phi_S F_{UT}^{sin\phi_S} + sin(2\phi_h - \phi_S) F_{UT}^{sin(2\phi_h-\phi_S)}\right)\Big]$$
$$+ |S_\perp| h_l \Big[\sqrt{1-\varepsilon^2} cos(\phi_h - \phi_S) F_{LT}^{cos(\phi_h-\phi_S)}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_S F_{LT}^{cos\phi_S} + cos(2\phi_h - \phi_S) F_{LT}^{cos(2\phi_h-\phi_S)}\right)\Big]\Big\},$$

Cahn & Boer-Mulders

unpolarised target

longitudinaly polarised target

transversely polarised target

Sivers
Collins
Pretzelosity
Worm Gear

A catalog of PDFs

SIDIS cross section decomposition LO

$$\frac{d\sigma}{xdyd\phi_S d\phi_h dz_h dP_{hT}^2} = \frac{e^4}{32\pi^2 x Q^2}\frac{y}{1-\varepsilon}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon\, F_{UU,L} + \varepsilon\, cos(2\phi_h) F_{UU}^{cos2\phi_h}$$
$$+\sqrt{2\varepsilon(1-\varepsilon)}\left(cos\phi_h F_{UU}^{cos\phi_h} + h_l sin\phi_h F_{LU}^{sin\phi_h}\right)$$
$$+S_\parallel\left[\sqrt{2\varepsilon(1+\varepsilon)} sin\phi_h F_{UL}^{sin\phi_h} + \varepsilon\, sin(2\phi_h) F_{UL}^{sin2\phi_h}\right]$$

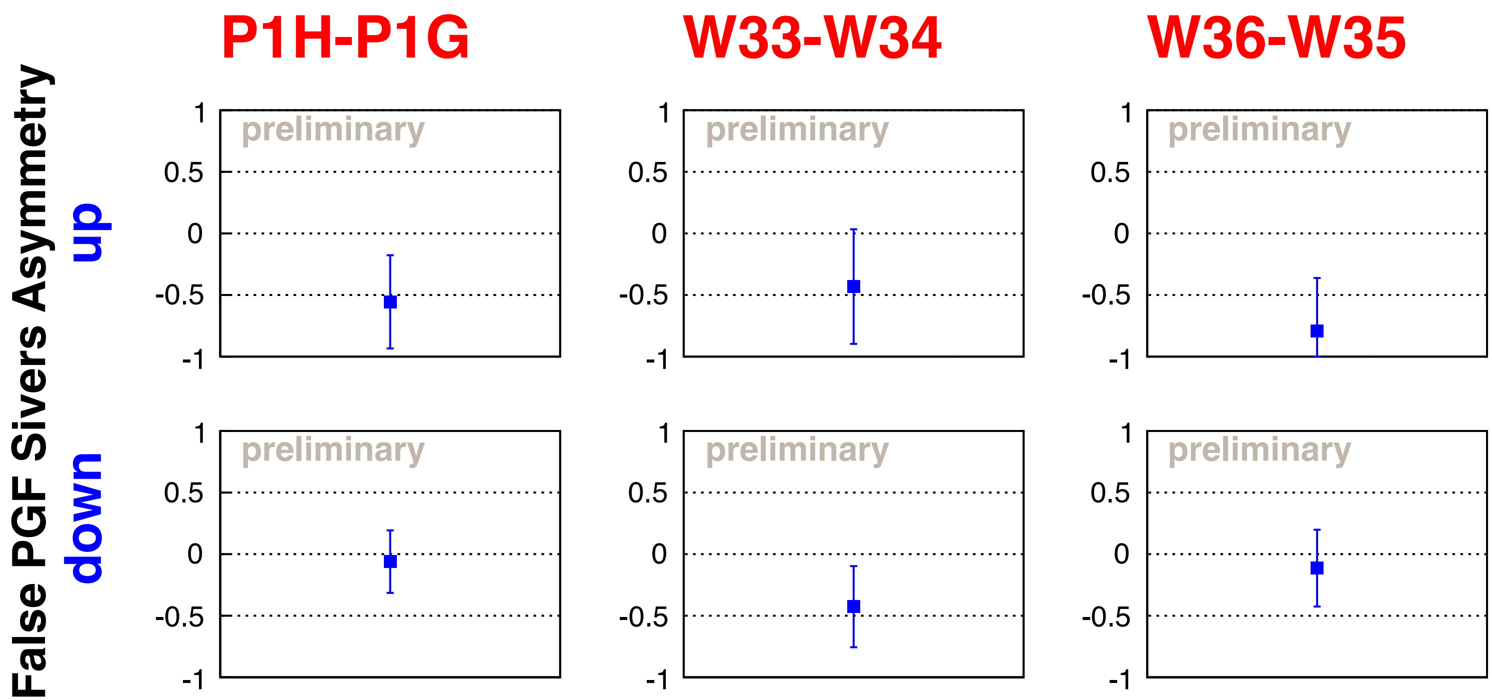
Cahn & Boer-Mulders

unpolarised target

get

$$F_{UU,T} \sim \sum_q e_q^2 \cdot f_1^q \otimes D_q^h, \qquad F_{LT}^{cos(\phi_h-\phi_S)} \sim \sum_q e_q^2 \cdot g_{1T}^q \otimes D_q^h,$$
$$F_{LL} \sim \sum_q e_q^2 \cdot g_{1L}^q \otimes D_q^h, \qquad F_{UT,T}^{sin(\phi_h-\phi_S)} \sim \sum_q e_q^2 \cdot f_{1T}^{\perp q} \otimes D_q^h,$$
$$F_{UU}^{cos2\phi_h} \sim \sum_q e_q^2 \cdot h_1^{\perp q} \otimes H_1^{\perp q}, \qquad F_{UT}^{sin(\phi_h+\phi_S)} \sim \sum_q e_q^2 \cdot h_1^q \otimes H_1^{\perp q},$$
$$F_{UL}^{sin2\phi_h} \sim \sum_q e_q^2 \cdot h_{1L}^{\perp q} \otimes H_1^{\perp q}, \qquad F_{UT}^{sin(3\phi_h-\phi_S)} \sim \sum_q e_q^2 \cdot h_{1T}^{\perp q} \otimes H_1^{\perp q}.$$

Falses

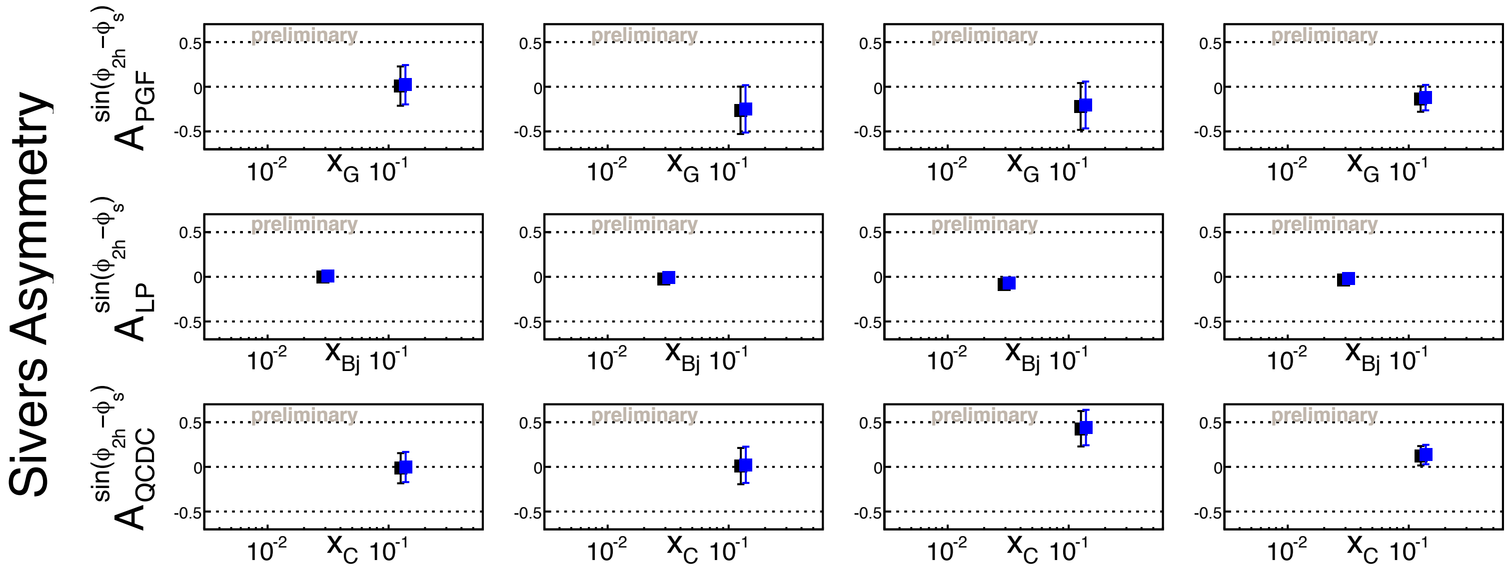


P1H-P1G
W33-W34
W36-W35
False PGF Sivers Asymmetry
up
down
preliminary
1
0.5
0
-0.5
-1

1% false test for asymmetry

standard **1% false**

P1H-P1G **W33-W34** **W36-W35** **final**



Correlations