Transverse-Momentum Dependent Transverse Spin Asymmetries in COMPASS Drell-Yan data

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on behalf of the COMPASS Collaboration

Twist-2 TMD PDFs

Nucleon

k_T — Quark spin — Nucleon spin

Quark Polarisation \ Nucleon Polarisation	Unpol.	L	T
Unpol.	$f_1^q(x,\boldsymbol{k}_T^2)$		$f_{1T}^{q\perp}(x,\boldsymbol{k}_T^2)$ **Sivers**
L		$g_{1L}^q(x,\boldsymbol{k}_T^2)$ **helicity**	$g_{1T}^q(x,\boldsymbol{k}_T^2)$ **Kotzinian—Mulders**
T	$h_1^{q\perp}(x,\boldsymbol{k}_T^2)$ **Boer—Mulders**	$h_{1L}^{q\perp}(x,\boldsymbol{k}_T^2)$ **worm-gear L**	**pretzelosity** $h_{1T}^{q\perp}(x,\boldsymbol{k}_T^2)$ **transversity** $h_1^q(x,\boldsymbol{k}_T^2)$

Quark

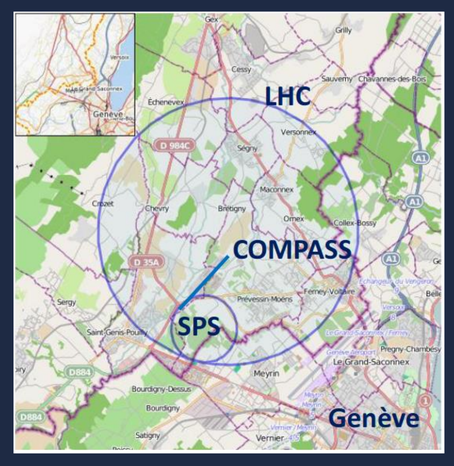
What is the magnitude of the orbital angular momentum contribution to the proton spin?

In quark models, **pretzelosity** is linked to the difference between **helicity** and **transversity** distributions. What does this suggest about the role of quark orbital angular momentum in nucleon spin structure?

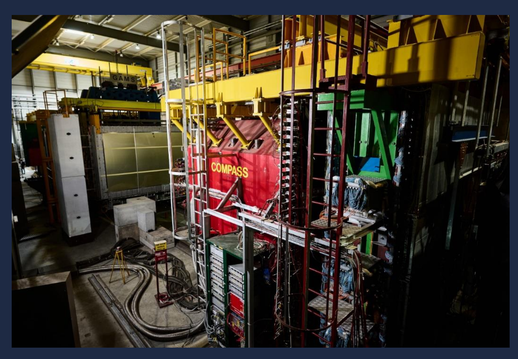
What is the net polarisation of quarks inside an unpolarised proton?

How strongly is the transverse spin of the quark correlated with the transverse spin of the nucleon?

Common Muon and Proton Apparatus for Structure and Spectroscopy



Fixed target, multi-purpose experiment located in the CERN North Area, along the SPS M2 beam.



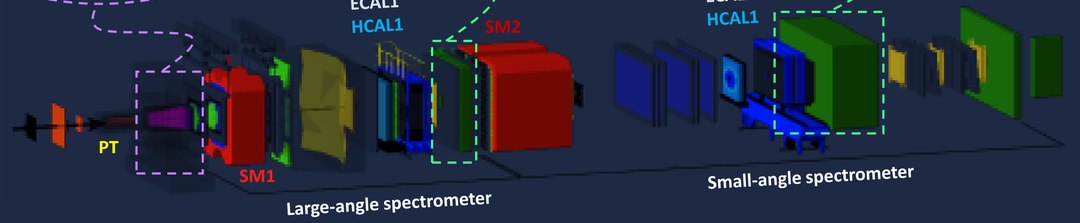
Broad research programme in hadron structure and hadron spectroscopy.

Drell-Yan setup

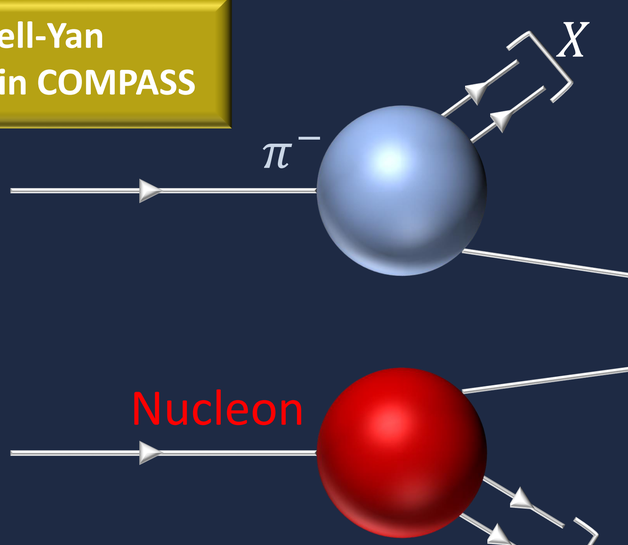
- High energy negative hadron beam (190 GeV) with a composition of **97% π^-**, 2% K^-, 1% p^-
- Targets: polarised NH_3, unpolarised Al and W
- Two spectrometer stages for a wide phase-space coverage

The **hadron absorber** blocks hadrons without affecting muons.

Muon filters (**MF**s) are used to detect muons, which serve as signatures of Drell–Yan events.



Drell-Yan process in COMPASS



At leading order, the differential cross section for pion-induced Drell-Yan lepton-pair production off a transversely polarized nucleon can be expressed as:

$$\frac{d\sigma_{LO}}{d\Omega d^4q} \propto 1 + D_{\sin^2\theta_{CS}}\cos(2\varphi_{CS})A_U^{\cos(2\varphi_{CS})} + |S_T|\left[\sin(\varphi_S)A_T^{\sin(\varphi_S)} + D_{\sin^2\theta_{CS}}\left(\sin(2\varphi_{CS}+\varphi_S)A_T^{\sin(2\varphi_{CS}+\varphi_S)} + \sin(2\varphi_{CS}-\varphi_S)A_T^{\sin(2\varphi_{CS}-\varphi_S)}\right)\right]$$

$\varphi_{CS}, \theta_{CS}$ – azimuthal and polar angles in the Collins–Soper frame
φ_S –azimuthal angle in the target rest frame
$D_{\sin^2\theta_{CS}}$ – virtual-photon depolarization factor
S_T – nucleon transverse polarization

$A_U^{\cos(2\varphi_{CS})} \propto h_{1,\pi}^{q\perp} \otimes h_{1,N}^{q\perp}$ $\quad A_T^{\sin(\varphi_S)} \propto f_{1,\pi}^{q} \otimes f_{1T,N}^{q\perp}$ $\quad A_T^{\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{q\perp} \otimes h_{1T,N}^{q\perp}$ $\quad A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,N}^{q}$

The convolution of the TMDs cannot be disentangled without assumptions about the dependence of the PDFs on the intrinsic transverse momenta k_T of the partons.

WTSAs: asymmetries weighted by the transverse momentum of γ^*

WTSAs are related to k_T^2-moments , defined as $f^{(n)}(x) = \int d^2k_T \left(\frac{k_T^2}{2M^2}\right)^n f(x,k_T^2)$, where M is the hadron mass.

TSA

$A_T^{\sin(\varphi_S)} \propto f_{1,\pi}^{q} \otimes f_{1T,N}^{q\perp}$

$A_T^{\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{q\perp} \otimes h_{1T,N}^{q\perp}$

$A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{q\perp} \otimes h_{1,N}^{q}$

$A_T^{W_\Phi \sin\Phi} = \int d^2\boldsymbol{q}_T W_\Phi A_T^{\sin\Phi}$

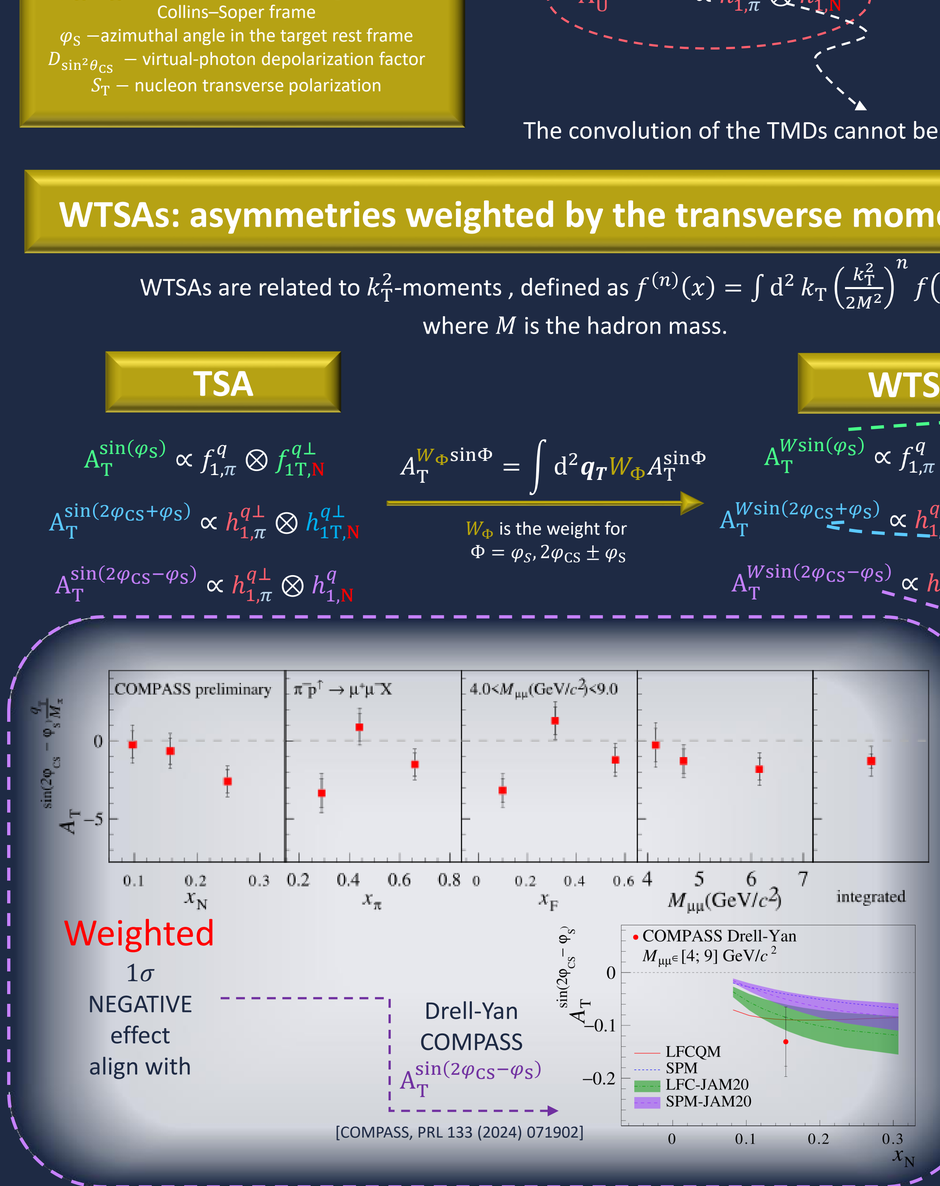
W_Φ is the weight for $\Phi = \varphi_S, 2\varphi_{CS} \pm \varphi_S$

WTSA

$A_T^{W\sin(\varphi_S)} \propto f_{1,\pi}^{q} \times f_{1T,N}^{q\perp(1)}$

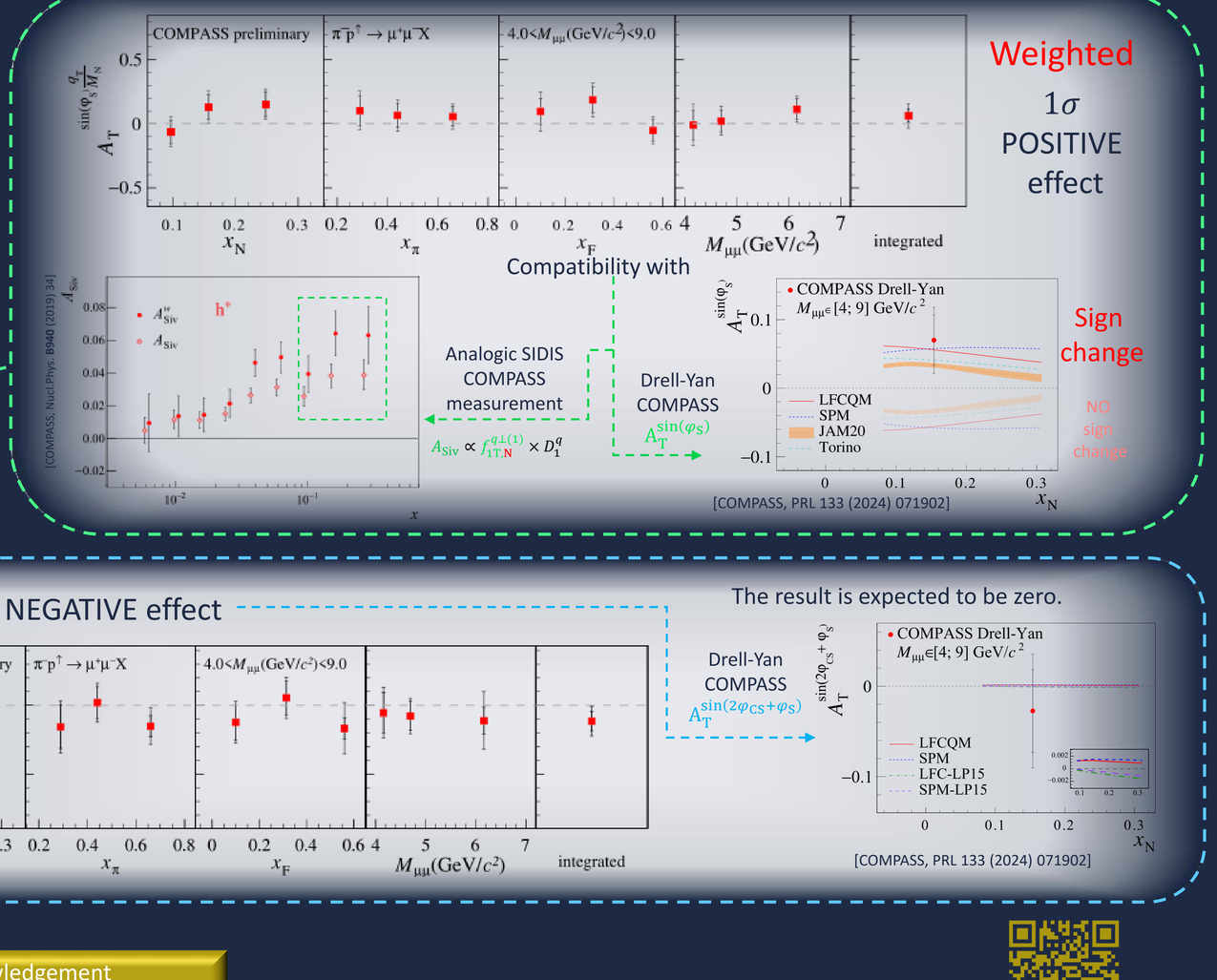
$A_T^{W\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{q\perp(1)} \times h_{1T,N}^{q\perp(2)}$

$A_T^{W\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{q\perp(1)} \times h_{1,N}^{q}$



Weighted 1σ NEGATIVE effect align with Drell-Yan COMPASS $A_T^{\sin(2\varphi_{CS}-\varphi_S)}$

[COMPASS, PRL 133 (2024) 071902]



Weighted 1σ POSITIVE effect

Compatibility with Analogic SIDIS COMPASS measurement $A_{Siv} \propto f_{1T,N}^{q\perp(1)} \times D_1^q$ Drell-Yan COMPASS $A_T^{\sin(\varphi_S)}$

[COMPASS, PRL 133 (2024) 071902]

Sign change

NO sign change

Weighted 1σ NEGATIVE effect

The result is expected to be zero.

Drell-Yan COMPASS $A_T^{\sin(2\varphi_{CS}+\varphi_S)}$

[COMPASS, PRL 133 (2024) 071902]

Acknowledgement

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