Odderon/gluon Sivers searches at EIC

Yoshitaka Hatta

(BNL)

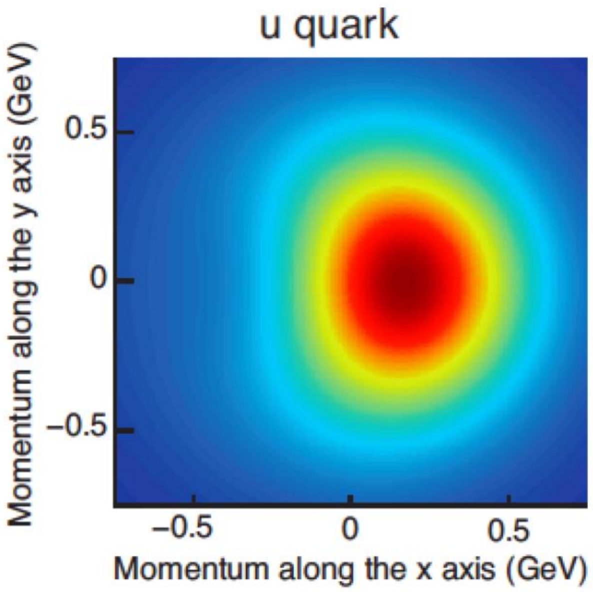
R. Boussarie, YH, L. Szymanowski, S. Wallon

Phys.Rev.Lett. 124, 172501 (2020); arXiv:1912.08182

Sivers function

Spin-momentum correlation in a transversely polarized proton
Lots of studies due to its connection to Single Spin Asymmetry (SSA)

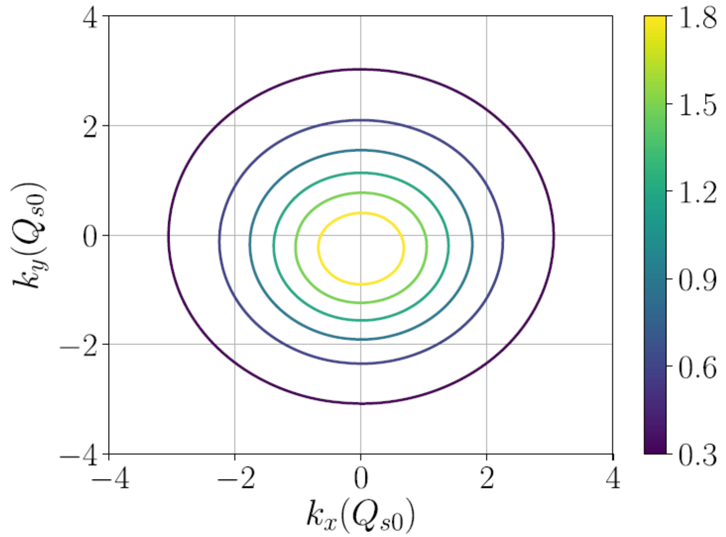
$$f(x,k_\perp) = f_0(x,k_\perp) + (\vec{S}_\perp \times \vec{k}_\perp)\cdot \hat{p} f_{1T}^{\perp}(x,k_\perp)$$



Prokudin; white paper

Gluon Sivers can also be studied at EIC
→ SSA of open charm, dijet,…

Zheng, Aschenauer, Lee, Xiao, Yin; 1805.05290



Yao, Hagiwara, YH; 1812.03959

Sivers function: a different look

TMD

$$f(x,k_\perp) = f_0(x,k_\perp) + (\vec{S}_\perp \times \vec{k}_\perp)\cdot \hat{p} f_{1T}^\perp(x,k_\perp)$$

More properly,
use the nucleon spinor

$$k_\perp^i \bar{u}(PS_\perp)\sigma^{+i}u(PS_\perp)f_{1T}^\perp(x,k_\perp)$$

GTMD

$$k_\perp^i \bar{u}(P'S')\sigma^{+i}u(PS)F_{12}(x,k_\perp,\Delta_\perp)$$

Reduces to Sivers in the
forward limit

This spinor product is also nonvanishing if longitudinally polarized $S^\mu = S_L^\mu$
and if helicity flips $S^\mu = -S'^\mu$

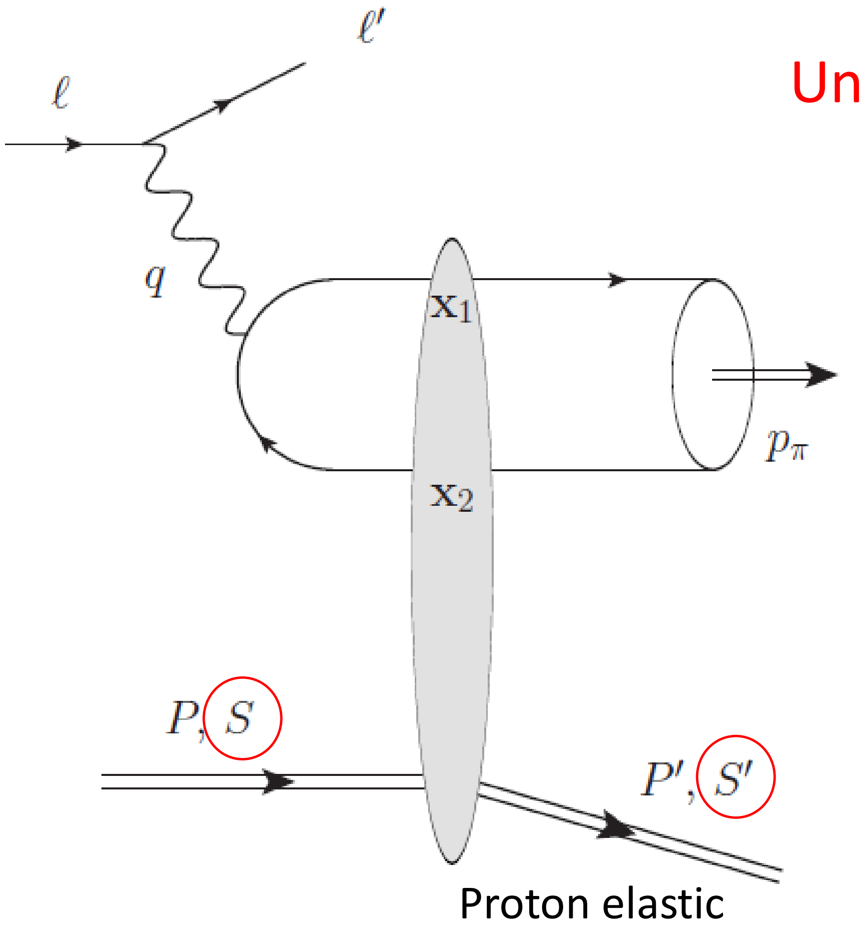
$$\bar{u}(P, -S_L)\sigma^{+i}u(PS_L) = (\pm i, -1)$$

helicity

→ Sivers function can enter certain near-forward, longitudinal helicity-flip processes.

→ It can also enter unpolarized cross sections where the initial and final spins are summed (so that spin-flip amplitudes are automatically included).

Exclusive π^0 production at EIC



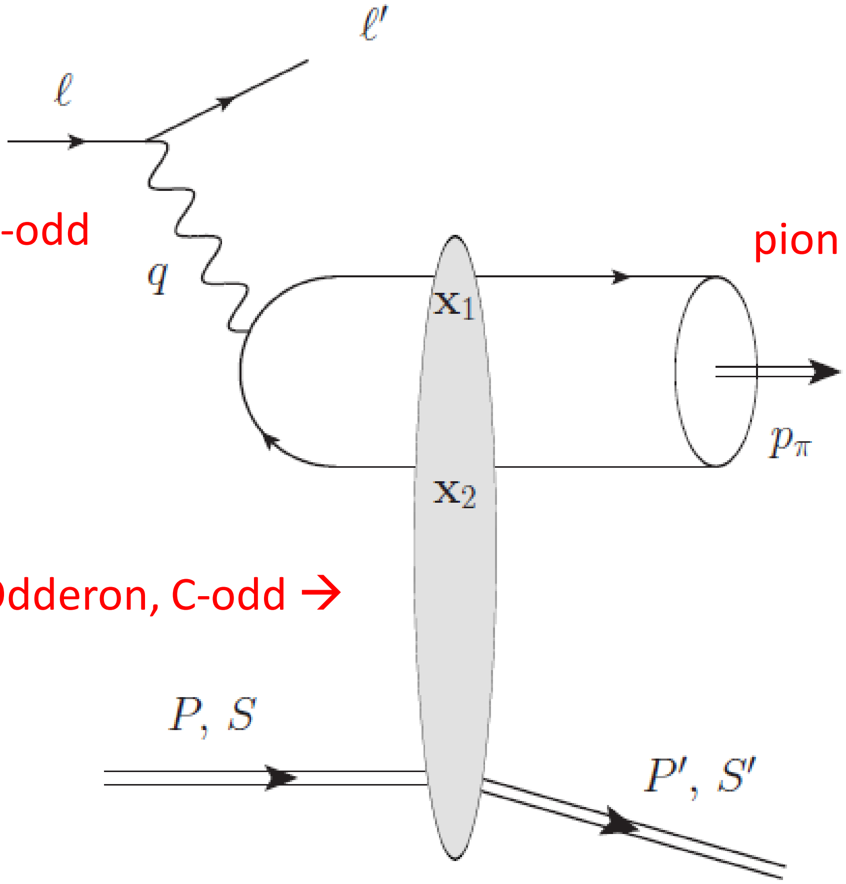
Unpolarized cross section at small-x, $t \approx 0$

$$\frac{d\sigma}{dt} = \sum_{SS'=\pm} \frac{d\sigma_{SS'}}{dt} \approx \frac{d\sigma_{+-}}{dt} + \frac{d\sigma_{-+}}{dt}$$

$$\frac{d\sigma}{dx_B dQ^2 d|t|} = \frac{\pi^5 \alpha_{em}^2 \alpha_s^2 f_\pi^2}{2^3 x_B N_c^2 M^2 Q^6} (1 - y + \frac{y^2}{2}) \times \left[\int_0^1 dz \frac{\phi_\pi(z)}{z\bar{z}} \int d\boldsymbol{k}^2 \frac{\boldsymbol{k}^2}{\boldsymbol{k}^2 + z\bar{z}Q^2} x f_{1T}^{\perp g}(x, \boldsymbol{k}^2) \right]^2$$

Cross section in the forward limit is dominated by gluon Sivers at small-x!

Connection to Odderon



Spin-dependent odderon
=gluon Sivers at small-x

Zhou; 1308.5912

Experimentally elusive for decades.
Finally found at the LHC? (TOTEM collaboration)

→ New connection between EIC and LHC

NEW DISCOVERY!

THE PARTICLE THAT'S NOT A PARTICLE

First proposed in the 1970s, the LHC may have finally found evidence of the elusive odderon

Reported by James Romero

What does the odderon tell us about the universe?

From glueballs and future technology to shining a light on the Standard Model, particle physicists assess the impact of the detection

The odderon as a standalone particle
"The main

Glueball detection
"There were many attempts to see the

Disproving naïve expectations
"A spectacular possible

Shining a light on the Standard Model
"This doesn't break the

Odderon tech
"When electrons were discovered, no one had

Confirming what we already knew
The experimental discovery of the odderon would not add much new information to our understanding of the universe. It has been known for quite a long time that the odderon firmly exists in QCD.
Valery Khoze, University of Durham

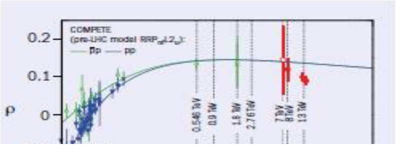
TOTEM

Oddball antics in proton–proton collisions

The TOTEM collaboration at CERN has uncovered possible evidence for a subatomic three-gluon compound called an odderon, first predicted in 1973. The result derives from precise measurements of the probability of proton–proton collisions at high energies, and has implications for our understanding of data produced by the LHC and future colliders.

In addition to probing the p… TOTEM is designed to meas… cross section of proton–prot… Physically it is by far the long… at the LHC, comprising two… 220 m on either side of the C… While most proton–proton i… the LHC cause the protons to… constituent quarks and gluon… detects the roughly 25% of el… that leave the protons intact. … merely cause the path of the p… deviate, by around a millime… distance of 200 m.

Elastic scattering at low-m…



… and … their own … treated like

… Sutter

POPULAR MECHANICS

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LHC Scientists Discover First Evidence of Particle Proposed Nearly 50 Years Ago

The odderon was first proposed in 1973, but actual evidence of its existence eluded scientists until now.

…lthough the new data favour the …tence of the odderon, the TOTEM …aboration prefers to emphasise all

how this ratio of scattering amplitudes evolves as a function of the squared four-momentum transfer. A similar "forward"

"Revolutionary, if not heretical" was the phrase Nicolescu used in a recent

…evidence was supportive and the theory still very much had its critics. Back in 1990 at the annual Rencontres de Moriond conference of new ideas in physics, Nicolescu explained his continued belief in

TECH & SCIENCE

PARTICLE PHYSICS: WHAT'S AN ODDERON, AND DID CERN JUST REVEAL IT EXISTS?

BY KASTALIA MEDRANO ON 2/5/18 AT 9:30 AM EST

Gluon Sivers=Odderon in pp at the LHC

Elastic pp scattering, unpolarized

Hagiwara, YH, Pasechnik, Zhou; 2003.03680

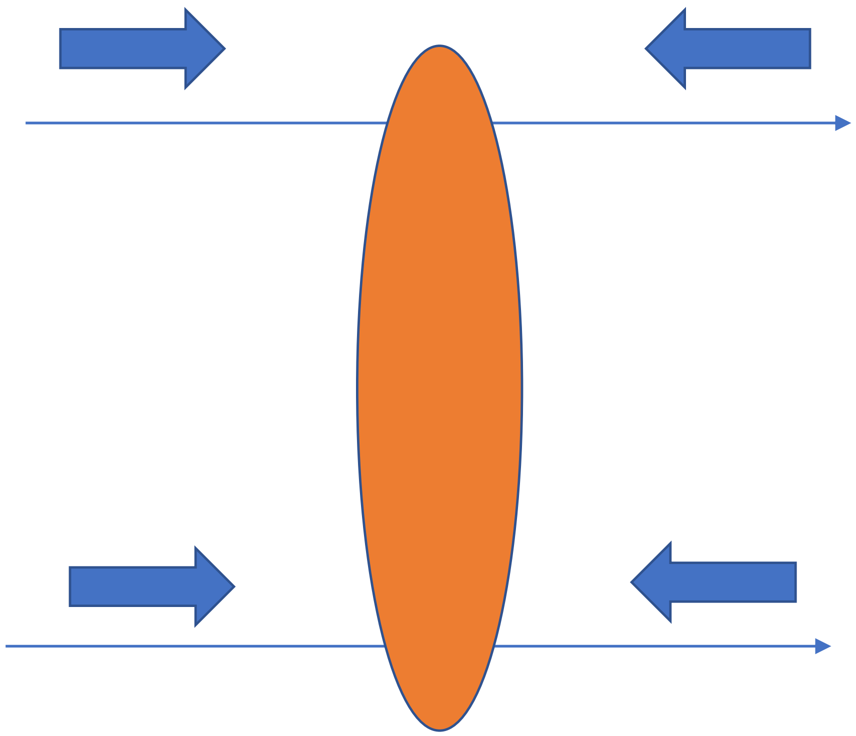
$$\frac{d\sigma}{dt} = \sum_{S_1S_2S_3S_4=\pm} \frac{d\sigma_{S_1S_2\to S_3S_4}}{dt}$$

Double helicity-flip from gluon Sivers=Odderon

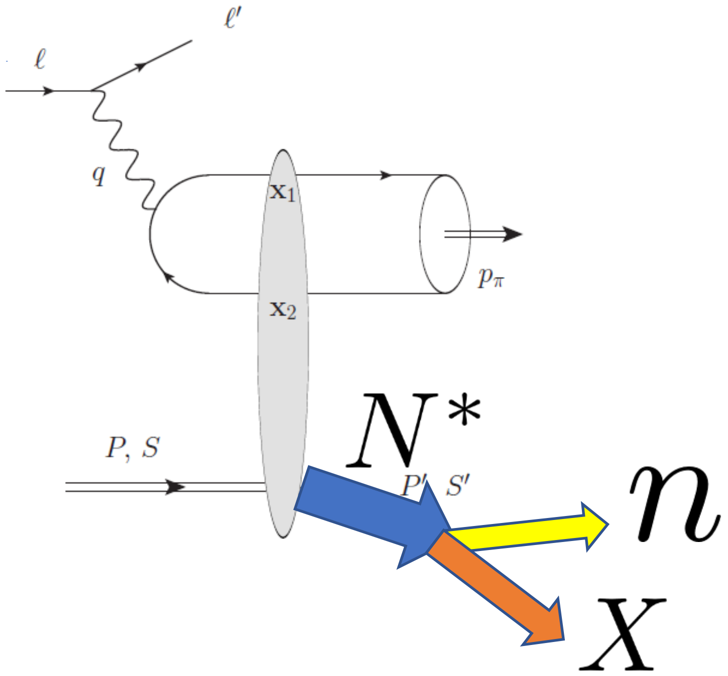
$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\sigma_{\rm tot}^2}{16\pi}(1+\rho^2+2|r_2|^2)$$

rho-parameter (spin non-flip)

$$\rho(s,t) = \frac{{\rm Re}T(s,t)}{{\rm Im}T(s,t)}$$



hep-ex/0206073

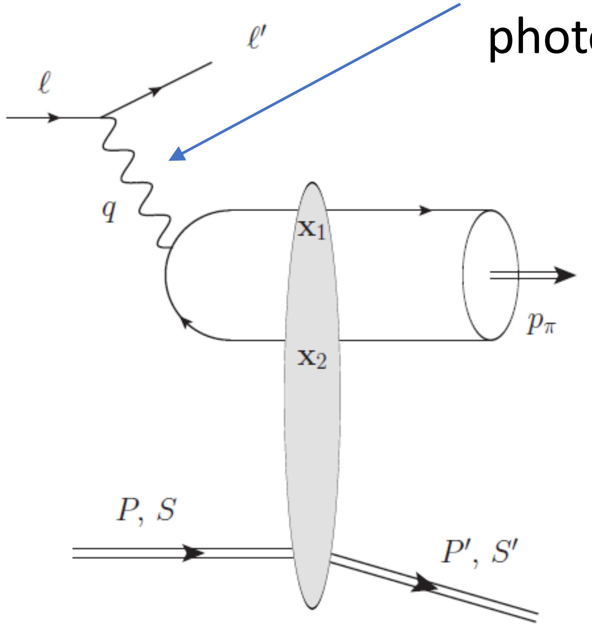


Search for Odderon-Induced Contributions to Exclusive π° Photoproduction at HERA

H1 Collaboration

Abstract

A search for contributions to the reaction $ep \rightarrow e\pi^\circ N^*$ from photon-Odderon fusion in the photoproduction regime at HERA is reported, at an average photon-proton centre-of-mass energy $\langle W \rangle = 215$ GeV. The measurement proceeds via detection of the π° decay photons, a leading neutron from the N^* decay, and the scattered electron. No π° signal is observed and an upper limit on the cross section for the photon-Odderon fusion process of $\sigma(\gamma p \rightarrow \pi^\circ N^*) < 49$ nb at the 95 % confidence level is derived, integrated over the experimentally accessible range of the squared four-momentum transfer at the nucleon vertex $0.02 < |t| < 0.3$ GeV^2. This excludes a recent prediction from a calculation based on a non-perturbative QCD model of a photon-Odderon fusion cross section above 200 nb.



Only the transversely polarized photon can contribute

Transverse polarization vector $\vec{\epsilon}_\perp$ has to be contracted by another transverse vector.

Naively, the only available vector is momentum transfer $\vec{\Delta}_\perp$

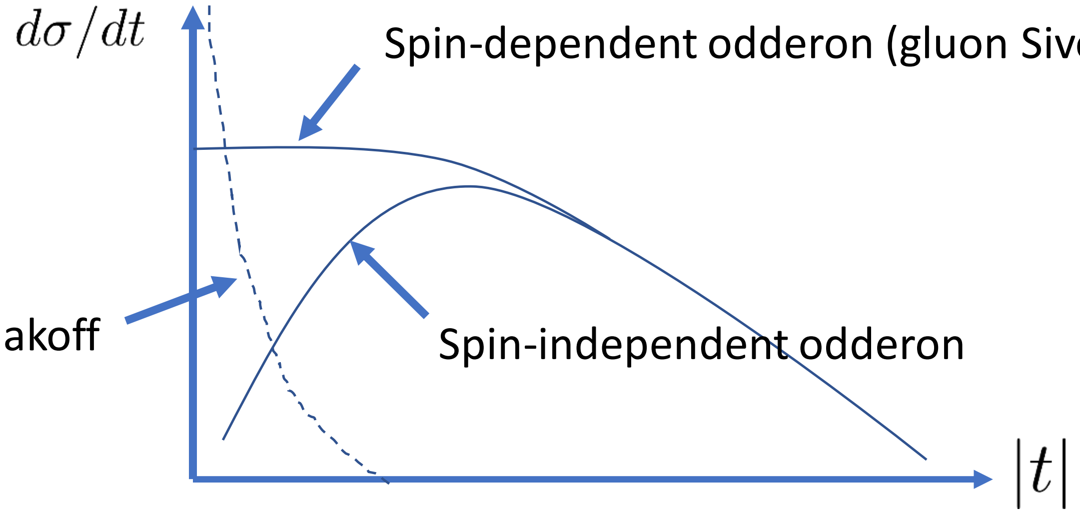
→ $d\sigma/dt$ vanishes as $t \to 0$

Theorists suggested to excite proton to a negative parity resonance.
(P-wave wavefunction contains a transverse vector.)
This is why H1 looked for neutrons from the decay $p \to N^* \to n$

But don't forget proton is a spin-1/2 particle.
We get a transverse vector when helicity flips

$$\bar{u}(P, -S_L)\sigma^{+i}u(PS_L) = (\pm i, -1)$$

$d\sigma/dt$ finite as $t \to 0$ without exciting proton!



H1 setup: kinematics

hep-ex/0206073

Integrated luminosity $30.6\ \text{pb}^{-1}$

Theory prediction $300\ \text{nb}$

H1 upper limit $< 49\ \text{nb}$

$\langle W \rangle = 215\ \text{GeV.}$

$Q^2 < 0.01\ \text{GeV}^2$ Photoproduction

$0.02 < |t| < 0.3\ \text{GeV}^2$

Background: Primakoff process $\gamma^{(*)}\gamma \to \pi^0$

H1 says `negligible' according to Pythia
(because they measured neutrons?
or because the predicted cross section is large?)

My comments

We don't have a prediction for the magnitude of the cross section...

Top EIC ep energy, top $\gamma^* p$ energy desirable

Theorists are more comfortable with $Q^2 > 1\text{GeV}^2$ ....

Larger $|t|$ is also interesting, probe spin-independent Odderons

Could be a serious background
if the odderon cross section is very small.

H1 setup, detectors

Neutron : Forward neutron calorimeter $\theta \lesssim 0.1$ mrad

$$E > 200\,\text{GeV} \quad (\leftrightarrow E_p^{beam} = 920\,\text{GeV})$$

$$t = (p - p')^2 \approx -(p_\pi^T)^2$$

Measured indirectly from pion momentum

Outgoing proton energy should be close to the beam energy in our case.

Recoiling proton and $t = (p - p')^2$ directly measurable at EIC

Pion: two-photon candidates with $M_{\gamma\gamma} < 335$ MeV

Two electromagnetic calorimeters

$153^\circ < \theta < 178^\circ$ $\quad$ $177.3^\circ < \theta < 179.4^\circ$

$E_\gamma > 90\,\text{MeV}$ $\quad$ $E_\gamma > 2\,\text{GeV}$

Electron: Electron tagger

Electron and two photons all in the backward region. Demand that their total momentum is within the region

$$49\ \text{GeV} < \sum_{i=e',\gamma,\gamma}(E - P_z)_i < 60\ \text{GeV}$$

i.e., close to 2 times the electron beam energy.

$$E_e^{beam} = 27.5\,\text{GeV}$$

Central detectors : ensure the presence of a gap

No charged particles allowed in $20^\circ < \theta < 160^\circ$

Results

$0.02 < |t| < 0.3\ \mathrm{GeV}^2$

Veto in central activity

$49\ \mathrm{GeV} < \sum_{i=e',\gamma,\gamma}(E - P_z)_i < 60\ \mathrm{GeV}$