

Diffraction and low- x 2024



Measurements of unpolarized cross section and transverse single spin asymmetry of Z^0 in 500/510 GeV $p+p$ collisions

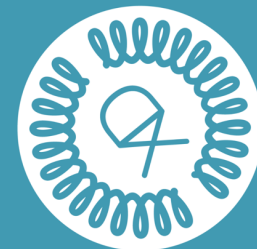
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Brookhaven National Laboratory

8-14 Sep 2024



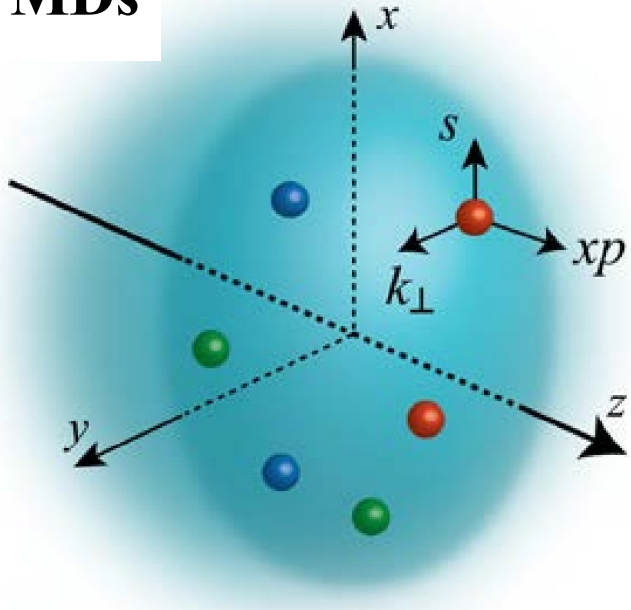
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Diffraction
and **LOW-X**

Cross section of Z^0

TMDs



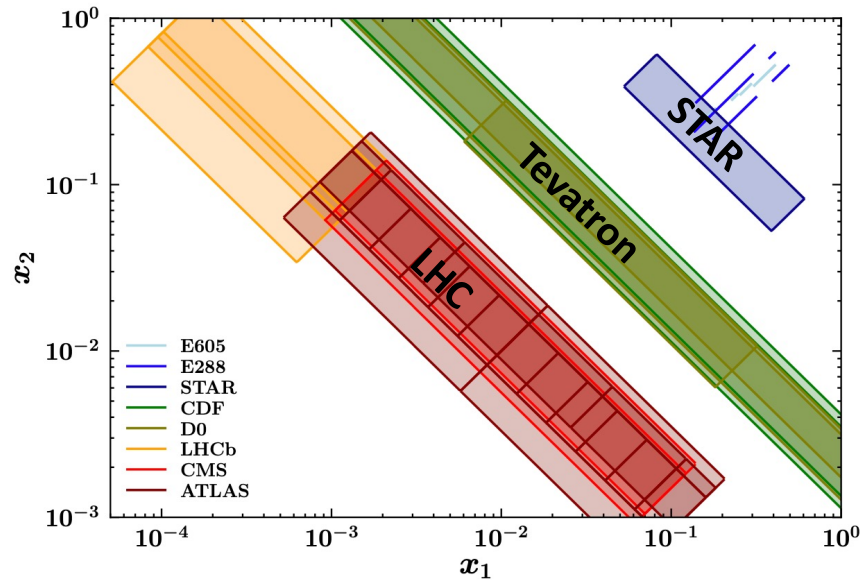
- **Motivation:** Understanding the **internal structure of nucleons** is an important topic in nuclear physics.
- **TMD Physics:** TMDs encode both the parton's **longitudinal momentum fraction** (x) and its intrinsic **transverse momentum** (k_T), depicting the density of partons in 3D.
- **Method:** Unpolarized TMDs extracted from $Z^0 p_T$ **spectrum** from $p+p \rightarrow Z^0 + X$; $\frac{d\sigma}{dQdydp_T} \propto \int f(x, k_T, Q^2) dk_T$, $k_T \ll Q \sim M_{Z^0}$ makes Z^0 an ideal observable.

*Transverse momentum dependent parton distribution functions (TMDs): $f(x, k_T, Q^2)$

Why Z^0 from RHIC-STAR

RHIC serves as an intermediate energy range:

- Complementary to other experiments with higher x
- Allowing studies in TMD **evolution on x**



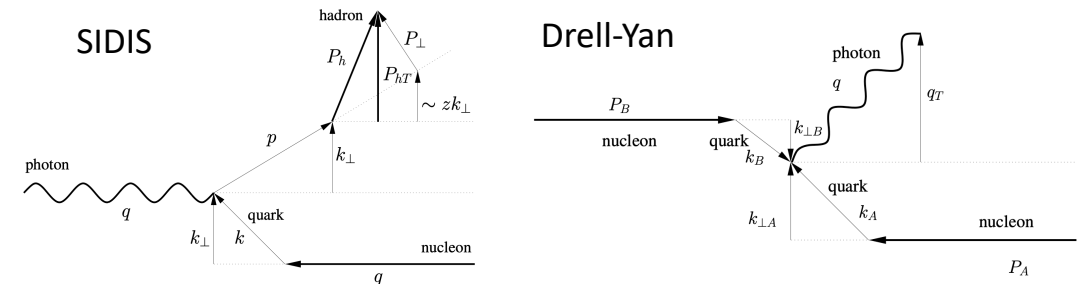
$$x \propto \frac{1}{\sqrt{s}}: x_{1,2} = Qe^{\pm y}/\sqrt{s}$$

A. Bacchetta et al., JHEP 07(2020) 117

Z^0 channel at STAR:

- Test property of TMDs from different processes
- Allowing studies in TMD **evolution on Q**

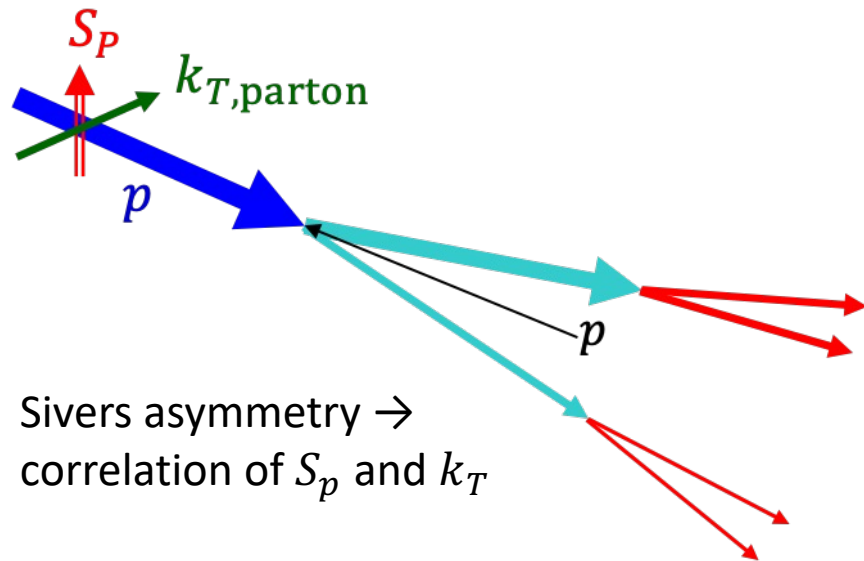
Channels	Experiments	Q
Z^0 boson	STAR, CDF, D0 ATLAS, CMS, LHCb	$\sim M_{Z^0}$
SIDIS	Hermes, Compass	Virtuality of γ^*
Drell-Yan	E288, E605, E772 PHENIX, ATLAS, D0	$\sim M_{ll}$



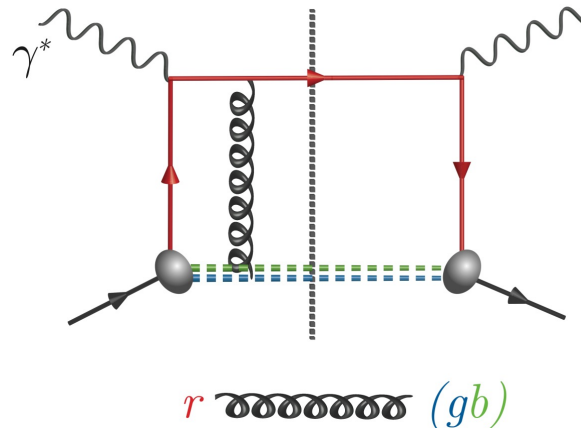
A. Bacchetta et al., JHEP 06(2017) 081

TSSA of Z^0

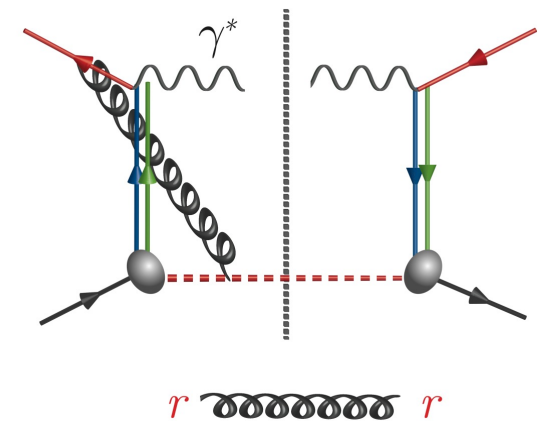
- Transverse single spin asymmetry (TSSA) of Z^0 is sensitive to Sivers function; RHIC is the world's only polarized pp collider who can make this measurement possible in p+p.
- TSSA of Z^0 is needed to test the non-universality of the Sivers function: **Sivers_{DIS} = - (Sivers_{DY} or Sivers_{W,Z0})**.



DIS: Color attractive

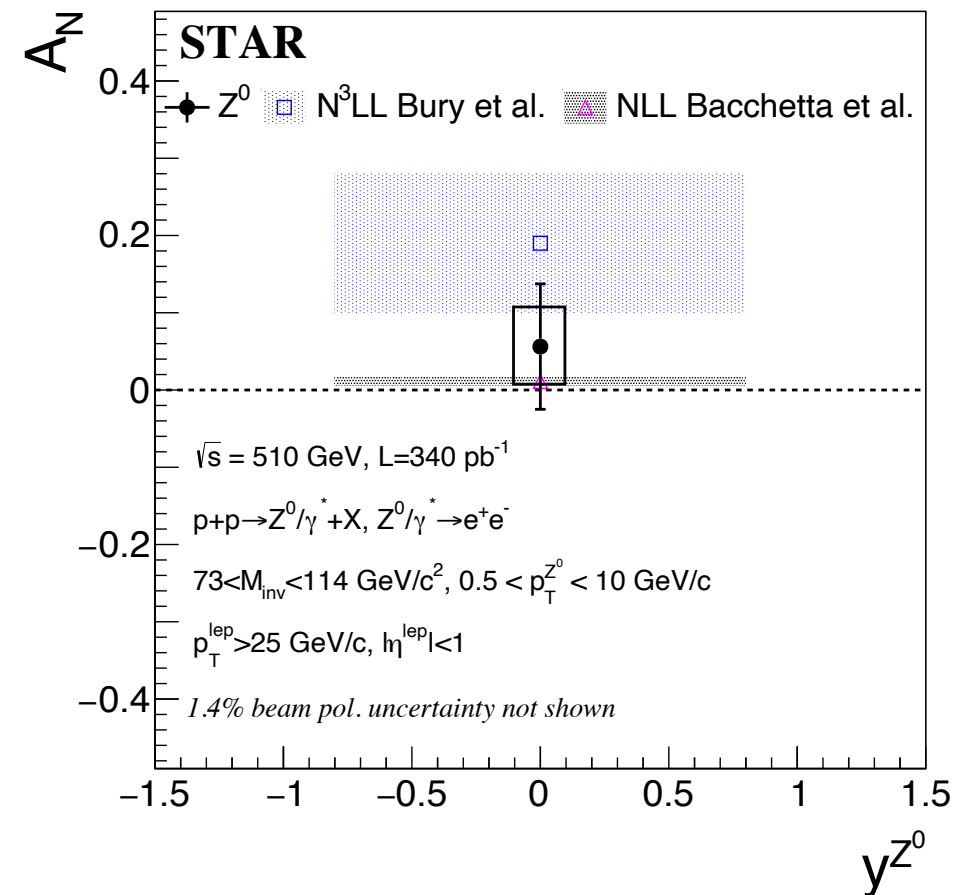
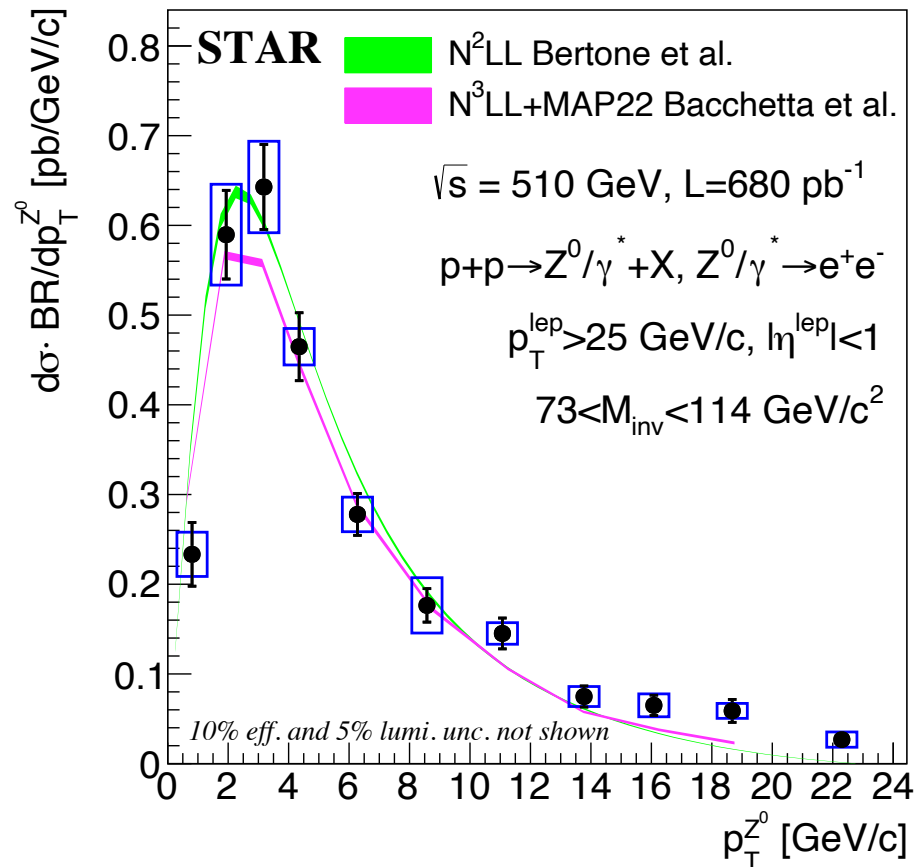


DY, W, Z^0 : Color repulsive



RHIC Spin Collaboration, RHIC Spin Plan

Results from STAR



- First measurement of the Z^0 differential cross section as a function of its p_T in p+p collisions at STAR.
- Cannot conclude sign change with STAR data; higher precision measurement (2022 data) is coming.

Please check out the poster!

STAR published these results in May 2024!

STAR, Phys. Lett. B 854 (2024) 138715



Physics Letters B
Volume 854, July 2024, 138715



Letter

Measurements of the Z^0/γ^* cross section and transverse single spin asymmetry in 510 GeV $p+p$ collisions

The STAR Collaboration

MEASUREMENTS OF THE Z^0 CROSS SECTION AND TRANSVERSE SINGLE SPIN ASYMMETRY IN 510 GEV PP COLLISIONS

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Abstract

The differential cross section for Z^0 boson production, measured as a function of the boson's transverse momentum p_T , provides critical insights into the evolution of transverse momentum-dependent parton distribution functions (TMDs). The transverse single spin asymmetry (A_N , TSSA) of the Z^0 boson is particularly sensitive to one of the polarized TMDs, the Sivers function, which is predicted to have an opposite sign in $p+p \rightarrow W/Z+X$ processes compared to that observed in semi-inclusive deep inelastic scattering (SIDIS). In this poster, we present the first measurement of the Z^0 differential cross section as a function of p_T in $p+p$ collisions at a center-of-mass energy of 510 GeV, along with the total cross section as published by the STAR Collaboration. Additionally, we report the measurement of the Z^0 TSSA in transversely polarized $p+p$ collisions at 510 GeV.

Introduction

- The internal structure of protons, described by their parton distribution functions, is an important topic in theoretical, phenomenological, and experimental studies in nuclear physics.
- Transverse momentum dependent parton distribution functions (TMDs), which encode both the parton's longitudinal momentum fraction (x) and its intrinsic transverse momentum (\mathbf{k}_T), depict the density of partons in three dimensions.
- Experimentally, unpolarized TMDs can be extracted from Z^0 boson p_T spectrum. If the transverse momentum of the lepton pair is sufficiently small compared to Q , where Q is the mass of Z^0 . Additionally, the Sivers function, one of the polarized TMDs, can be probed through measurements of the transverse single spin asymmetry of Z^0 in polarized $p+p$ collisions.

STAR detector for Z^0 reconstruction

Main subsystems used to reconstruct Z^0 at STAR:

- Time Projection Chamber: $|n| < 1$, $\Delta\phi > 2\pi$, for lepton's charge, momentum.
- Barrel Electromagnetic Calorimeter: $|n| < 1$, $\Delta\phi > 2\pi$, for energy measurement.

STAR detector and $Z^0 \rightarrow e^+e^-$ event display

Why Z^0 measurement at STAR

$x \propto \frac{1}{\sqrt{s}} x_{1,2} = Qe^{y^*}/\sqrt{s}$

SIDIS Color attractive

DY, W, Z^0 : Color repulsive

RHIC operates at an intermediate collision energy:

- Provides complementary data to the LHC and Tevatron experiments.
- Offers access to the large x region, enabling studies of TMD evolution as a function of x .

Z^0 channel at STAR complements data to SIDIS measurement from other experiments, enabling studies of TMD evolution as a function of Q^2 .

As the world's only polarized $p+p$ collider, RHIC uniquely allows Z^0 TSSA measurements at STAR, providing an opportunity to test the non-universality of the Sivers asymmetry predicted in $p+p$ collisions compared to that in SIDIS.

A. Bacchetta et al., JHEP 07(2020)117 RHIC Spin Collaboration, RHIC Spin Plan

p_T spectrum of Z^0

Total cross section of Z^0

A_N of Z^0

STAR published these results in May 2024!
STAR, Phys. Lett. B 854 (2024) 138715

- p_T spectrum: It is the first measurement of the Z^0 differential cross section as a function of its p_T in $p+p$ collisions at a center-of-mass energy of 510 GeV by the STAR experiment, using data collected from 2011-2013 and 2017.
- Total cross section: New results agree with the prior published results, with higher statistics.
- TSSA: The measured A_N is 0.056 ± 0.081 (stat) ± 0.050 (sys). Main systematic uncertainty comes from the like sign background.

Summary and outlook

- The p_T spectrum of the Z^0 measured at STAR, together with results from other experiments on DY, SIDIS, and Z^0 , provide important constraints on the x and Q^2 evolution as well as the process dependence of the unpolarized TMDs.
- The result of A_N can accommodate the sign change hypothesis that is based on the non-universality property of the Sivers function between $DY/Z^0/W$ production and SIDIS. It cannot conclusively verify the prediction.
- Precision will be improved using $p+p$ data at 508 GeV that STAR collected in 2022.

Acknowledgements

We thank the STAR Collaboration, RHIC Operations Group and RCF at BNL. Special thanks go to my collaborators: Elke-Caroline Aschmauer and Salvatore Fazio.



Thank you!