Polarized Drell–Yan experiment SpinQuest at Fermilab

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on behalf of the SpinQuest Collaboration

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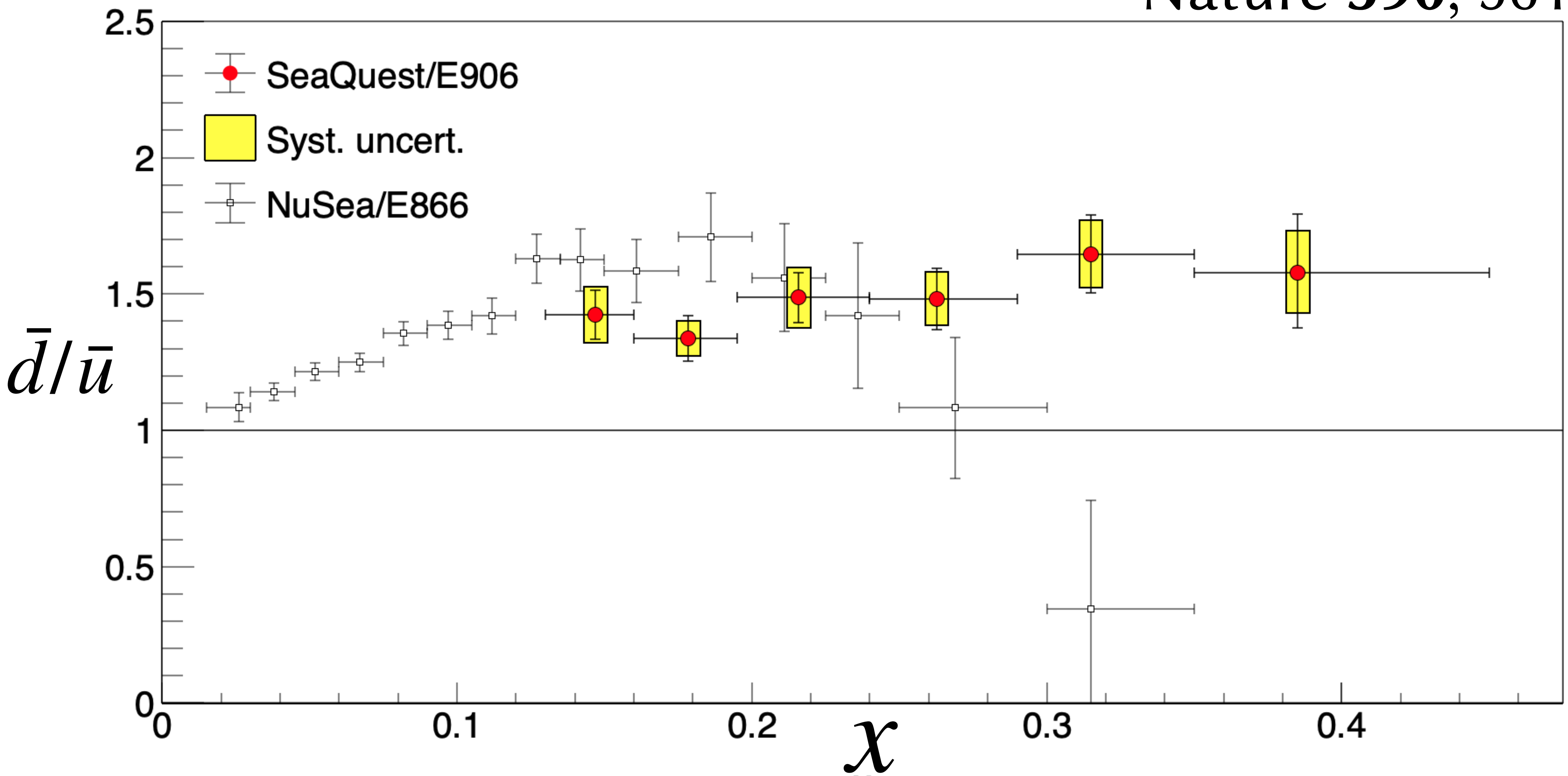
SeaQuest Proton antiquark flavor asymmetry $\bar{d}/\bar{u}$

February 2021: The asymmetry of antimatter in the proton

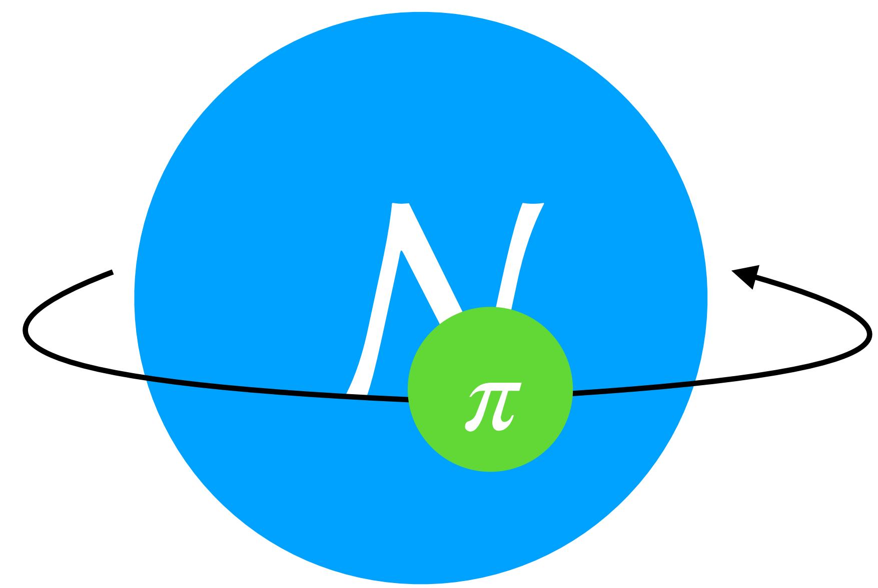
Nature **590**, 561 (2021)



- Antiquark flavor asymmetry $\bar{d}/\bar{u}$ (antiquark PDF) of the proton at large x ($0.13 < x < 0.45$)
  - x: Bjorken x, momentum fraction of parton to the proton
- $\bar{d}/\bar{u} > 1.0$ in all measured range

Orbital Angular Momentum

- π could model
  - $|p\rangle = \alpha|p_0\rangle + \beta|N\pi^+\rangle + \gamma|\Delta^{++}\pi^-\rangle + \cdots$
    - ★ Superposition of baryon-meson state
    - ★ $\bar{d}$ is in π^+ of $|N\pi^+\rangle$
      - ✦ Naively imagine that π^+ floats around the neutron
    - ★ $\bar{u}$ is in π^- of $|\Delta^{++}\pi^-\rangle$
  - <u>The orbital angular momentum of antiquarks should be large</u>



The source of the flavor asymmetry can be investigated by measuring the contribution of OAM to proton spin

Proton Spin Puzzle

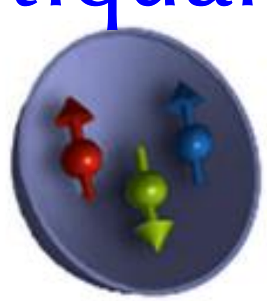
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma\ ?$$

-1980s

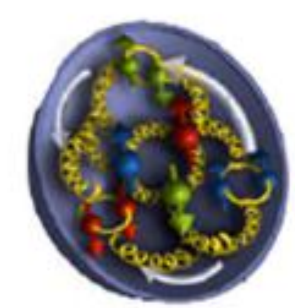
RHIC
gluon spin 30-50%
from $x = 0.05$ to $x = 0.2$

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

spin of quarks and antiquarks
~25%
EMC at CERN (1989)



Orbital Angular Momentum



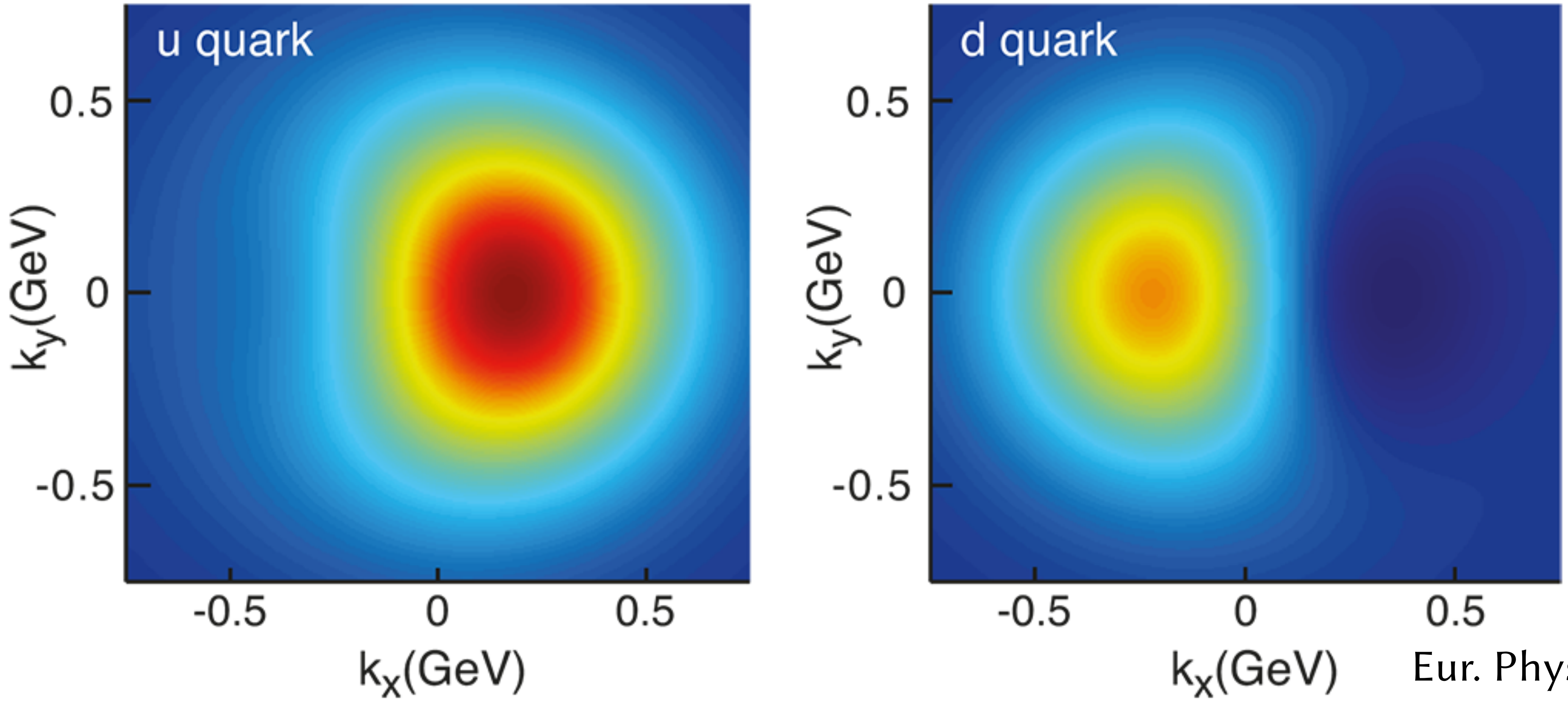
TMDs

TMDs

		Quarks		
		Unpolarized	Longitudinally Polarized	Transversally Polarized
Nucleon	U	f_1		$h_1^{\perp}$
	L		g_{1L}	$h_{1L}^{\perp}$
	T	$f_{1T}^{\perp}$ Sivers	$g_{1T}^{\perp}$	h_{1T}
				$h_{1T}^{\perp}$

- **<u>Sivers function</u>**
  - Transversely polarized target and unpolarized beam
  - Represent the relation between quark transverse momentum and nucleon spin
  - The non-zero Sivers function indicates the non-zero orbital motion of the parton
    - ★ Orbital angular momentum contribution on the proton spin

Sivers Effect



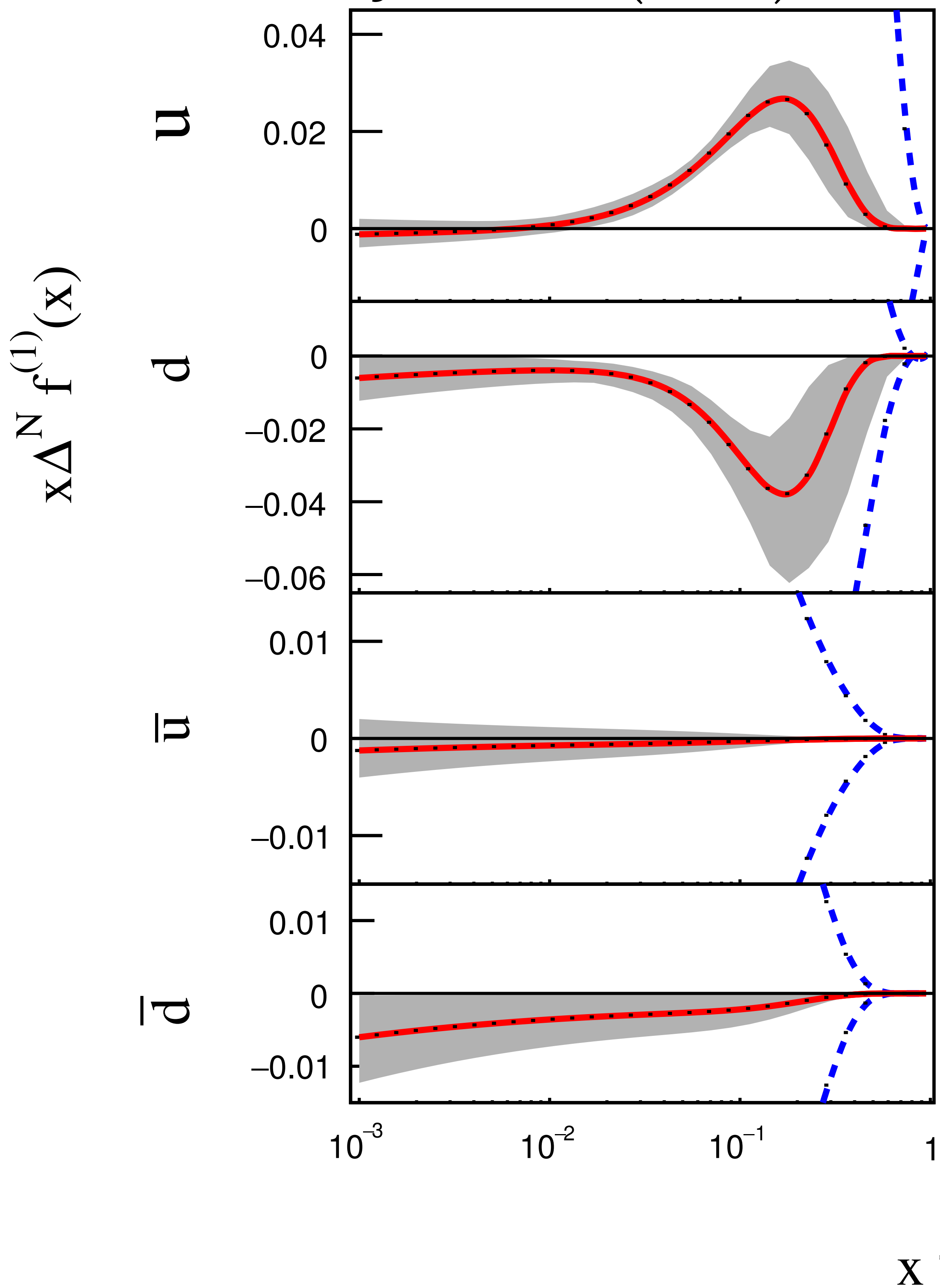
Eur. Phys. J. A (2016) 52: 268

- Demonstration of Sivers effect at $x = 0.1$
- The transverse momentum distribution is distorted due to the Sivers function (Sivers effect)

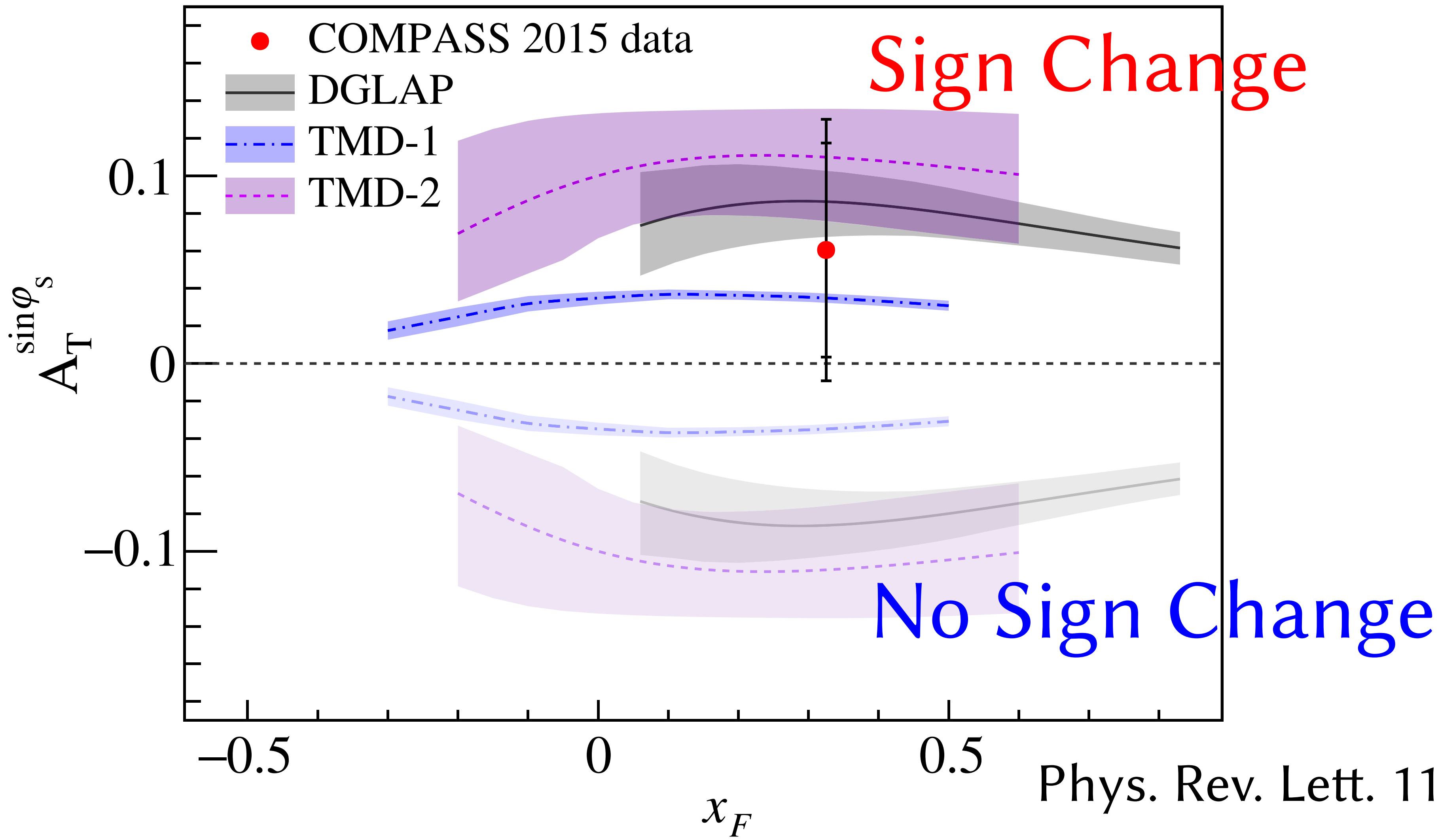
Measurements of Sivers Function

- Global analysis results of the experimental data
  - HERMES, COMPASS, JLab
- Sivers functions of u and d quarks are non-zero
  - Contribute to the proton spin
- Antiquarks Sivers functions are zero?
  - Reveal by the direct measurement – Drell–Yan process

JHEP 04 (2017) 046



Sign Change of Sivers Asymmetry

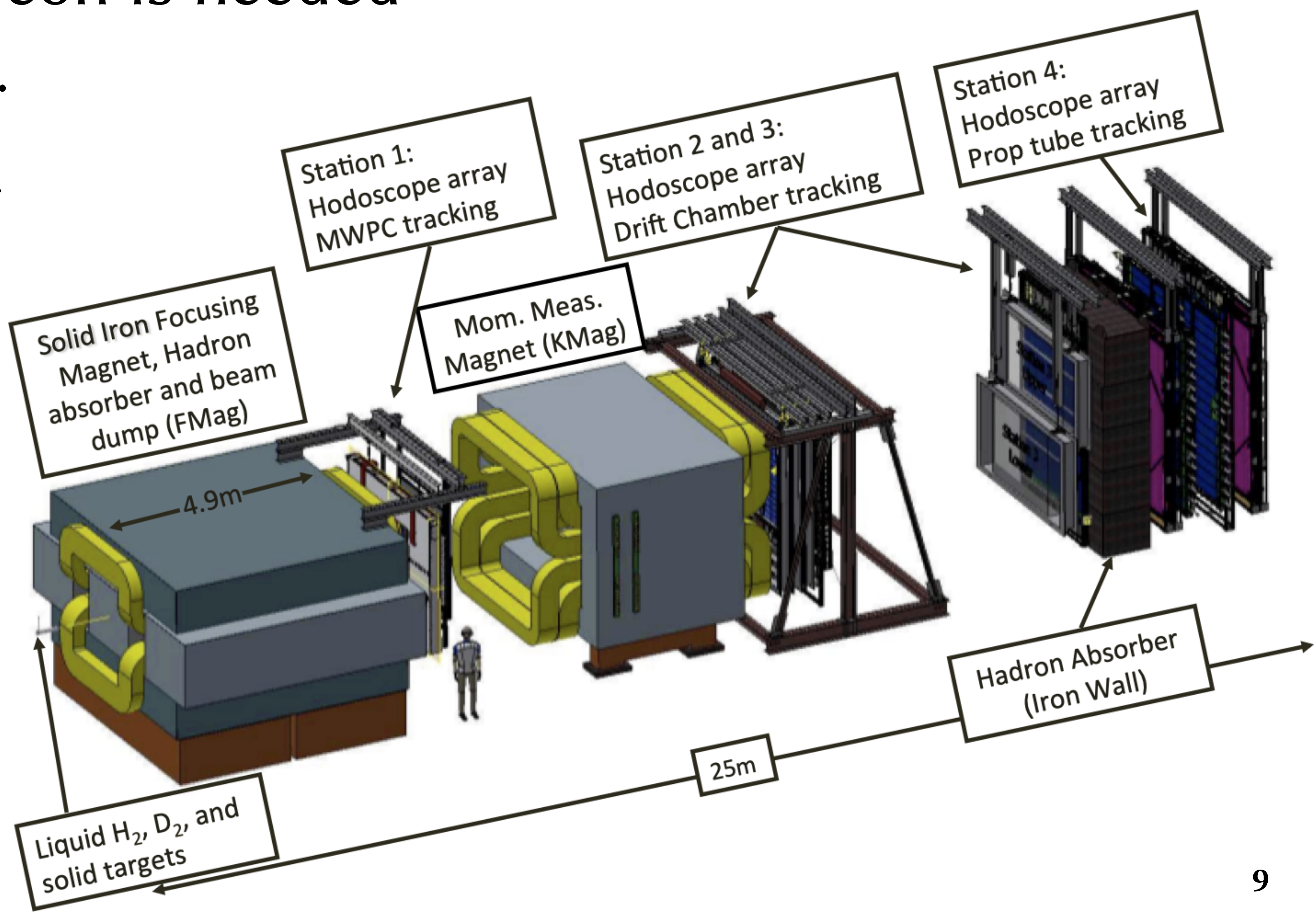


Phys. Rev. Lett. 119, 112002

- COMPASS has measured the Sivers asymmetry in Drell–Yan and indicated the sign of the asymmetry is opposite of that of SIDIS.
- Sign change of Sivers asymmetry of antiquarks may be investigated with SpinQuest results and future experiments results.

SpinQuest Spectrometer

- Basically the same spectrometer as SeaQuest
- SpinQuest will measure **antiquarks Sivers functions** via polarized Drell–Yan
  - First measurement of antiquarks Sivers functions
  - Transversally polarized nucleon is needed
    - ★ SeaQuest targets are unpol.
- Polarized targets are installed
  - NH3, ND3
  - 1.5 m upstream than SeaQuest to have better target/dump separation

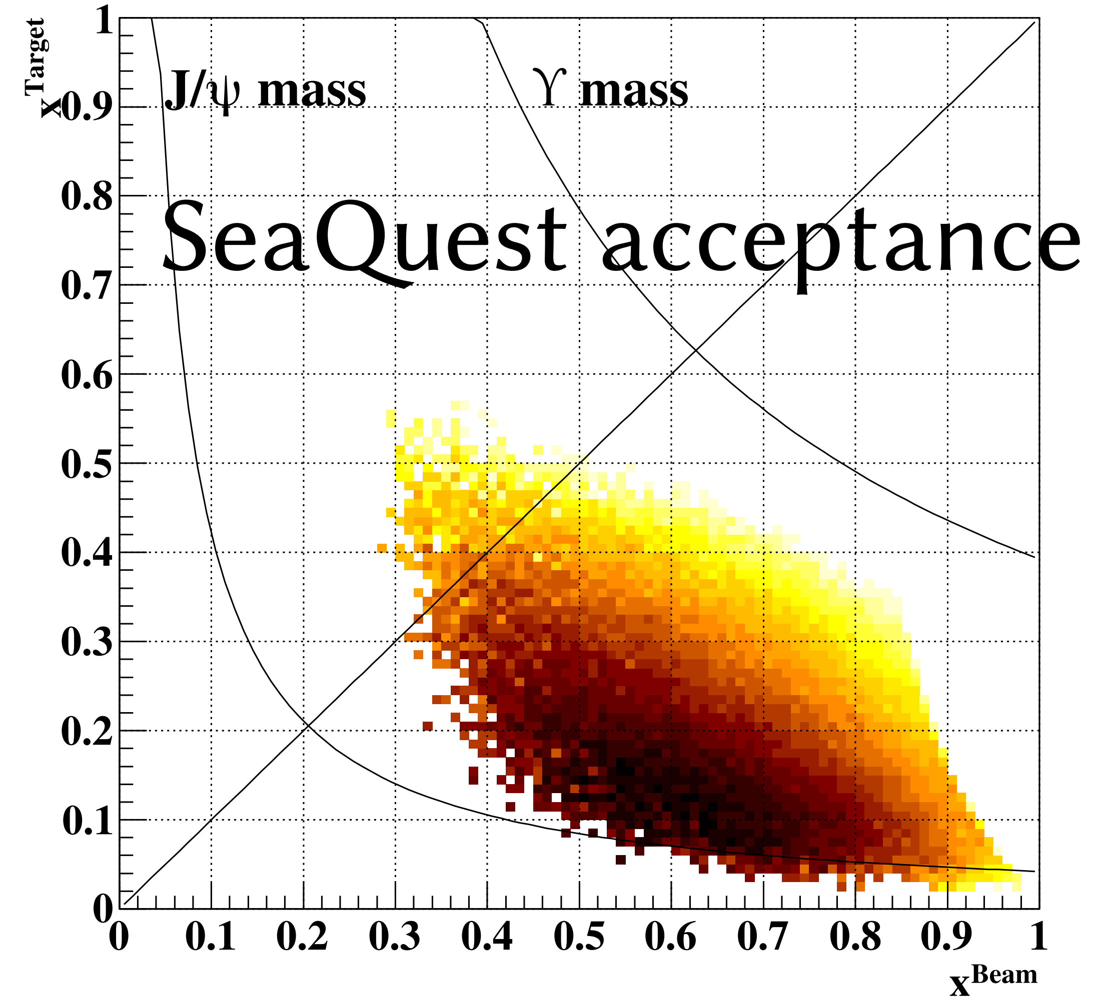


Sivers Asymmetry

- 120 GeV Proton beam + transversely polarized NH_3 and ND_3 targets

- $$A_N^{\text{Sivers}} \equiv \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \sim \frac{f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + f_{1T}^{\perp,q}(x_2) \cdot f_1^{\bar{q}}(x_1)}{f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + f_1^q(x_2) \cdot f_1^q(x_1)}$$

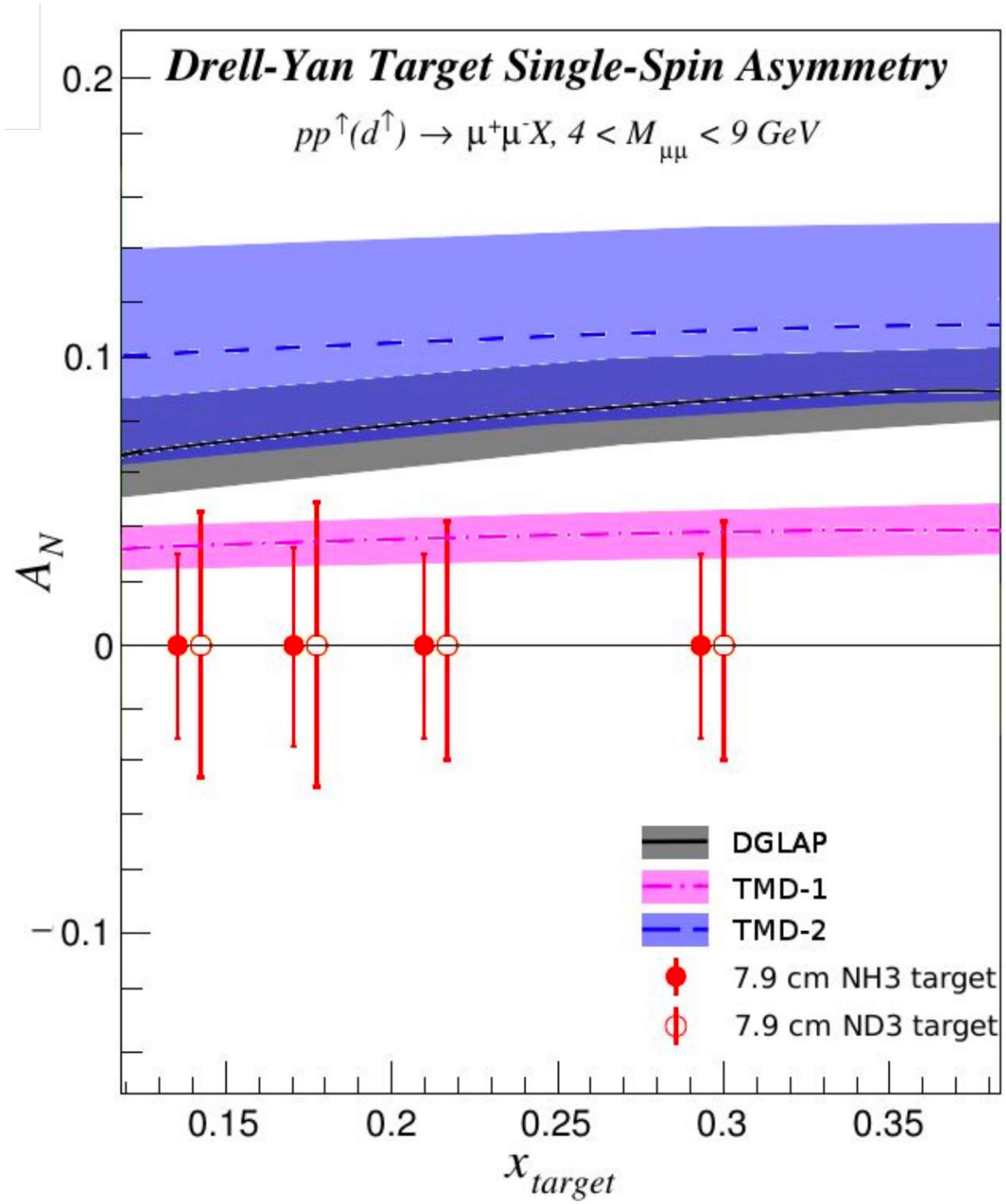
  - Magenta: Negligible because of forward detection
  - Red: Sivers function of antiquark in target
  - Blue: PDF of antiquark in target



SpinQuest Projection

- Current Status:
  - Polarized targets and detectors are ready for the data acquisition
  - Commissioning will start very soon (2023 Spring-Summer)
  - 2-year data acquisition is planned

- Single spin asymmetry A_N
  - $0.1 < x_{\text{target}} < 0.3$
  - Accuracy: $\delta_{A_N} \sim 0.04$



Summary

- Sivers function represents the relation between quark transverse momentum and nucleon spin.
  - Non-zero Sivers function $\longrightarrow$ Non-zero orbital angular momentum contribution to proton spin
- SpinQuest aims at the first direct measurement of the antiquark Sivers function.
  - Transversely polarized target Drell–Yan process is sensitive to the antiquark Sivers function measurement.
- Targets and detectors are ready for data acquisition.
  - Commissioning will start soon (2023 Spring-Summar).
  - 2-year data acquisition is planned