The Measurement of the Seaquark Sivers Asymmetry in Fermilab E1039 Polarized Drell-Yan Experiment

LANL: **M. Yurov**

E1039 SeaQuest collaboration

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WHY ARE WE DOING E1039?

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + L_{\bar{q}} + \Delta G + L_g$$

- need for a major breakthrough in understanding of the nucleon spin composition

Lattice QCD: K.-F. Liu *et al* arXiv:1203.6388

- importance of sea quarks

- account for spin of quarks and gluons - still missing ~half the picture

- sea quark OAM could be a major part of missing spin

- sea quarks contribution remains poorly constrained

- important to understand theoretically and experimentally

HINTS OF NON-ZERO OAM

- sea quarks flavor asymmetry observation - enhanced $\frac{\bar{d}}{\bar{u}}$ in E866

- pion cloud model as possible interpretation

$$|p\rangle \propto |p_0\rangle + |n\pi^+\rangle + |\Delta^{++}\pi^-\rangle + \dots$$

- needs to conserve parity: pions negative parity requires L=1

- if correct description - $|u\bar{d}\rangle$ possess OAM

- E866 results might point to sea quarks OAM

SIVERS FUNCTION

- explore correlation of quark motion relative to nucleon spin direction
- eight leading order Transverse Momentum Distributions (TMDs)
- **Sivers function** - transverse momentum distribution of unpolarized quarks in a transversely polarized proton

$$f_{1T}^\perp(x, k_T) = \begin{array}{c} \uparrow \\ \bigcirc \end{array} - \begin{array}{c} \downarrow \\ \bigcirc \end{array}$$

- proposed to explain results of experiments such as SSA in $pp^\uparrow \rightarrow \pi X$ (E704)
 - points to possible intrinsic k_T imbalance leads to asymmetry
- Sivers function vanishes if quarks have no OAM!

ACCESSING SEA QUARK SIVERS FUNCTION

$$e + p^\uparrow \rightarrow e' \pi X$$

① Polarized Semi-Inclusive DIS

$$A_{UT}^{SIDIS} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x) \otimes D_1^q(z)}$$

- L-R asymmetry in hadron production
- quark to hadron fragmentation function
- valence-sea quark: mixed

$$p + p^\uparrow \rightarrow \mu^+ \mu^- X$$

② Polarized Drell-Yan

$$A_N^{DY} \propto \frac{\sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2]}{\sum_q e_q^2 [f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2]}$$

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E1039 EXPERIMENT

ACCESSING SEA QUARK SIVERS FUNCTION

● has not been tried yet

- only experiment sensitive to sea quarks at large x

quark	SIDIS	Drell-Yan
valence	known	COMPASS
sea	poor sensitivity	unknown E1039

● selects sea quark from target

- $$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{9x_b x_t} \frac{1}{s} \sum_i e_i^2 \times \{q_i(x_b)\bar{q}_i(x_t) + \bar{q}_i(x_b)q_i(x_t)\}$$

- for E1039 kinematic configuration first term dominates

● measure Sivers asymmetry for both

- $\bar{u}(x), \bar{d}(x)$
- determine possible flavor asymmetry

$$p + p^\uparrow \rightarrow \mu^+ \mu^- X$$

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E1039 EXPERIMENT

FERMILAB E1039 EXPERIMENT

● FNAL 120GeV proton beam

- $\sqrt{S} = 15.5\text{GeV}$
- 5×10^{12} p/spill; 5 s/min
- 7.7×10^{17} protons on target/year

● SeaQuest E906 spectrometer

- 4 tracking station, trigger hodoscope
- focusing & analyzing magnets
- iron dump

● LANL/UVA polarized target

- solid NH_3, ND_3
- 5T field, 1K fridge
- μ -wave freq. P flip

FNAL proton beam
 $E_{\text{beam}} = 120\text{ GeV}$

$\gamma^* \rightarrow \mu^+\mu^-$

$$A_N(p_{\text{beam}} + p_{\text{trg}}^{\uparrow} \rightarrow DY) \propto \frac{N_L^{DY} - N_R^{DY}}{N_L^{DY} + N_R^{DY}} \propto \frac{f_{1T}^{\perp, \bar{u}}(x_t)}{f_1^{\bar{u}}(x_t)}$$

FERMILAB E1039 EXPERIMENT

asymmetry estimates from proposal (2013)

- sign and value of sea quark Sivers asymmetry
- sea quark Sivers flavor dependence
- if non-zero, "smoking gun" evidence for sea quark OAM

statistics estimates and kinematics coverage

Range x_2	Mean x_2	N events p	ΔA % p	N events n	ΔA % n
0.1-0.16	.139	5.0×10^4	3.2	5.8×10^4	5.4
0.16-0.19	0.175	4.5×10^4	3.3	5.2×10^4	5.7
0.19-0.24	0.213	5.7×10^4	2.0	6.6×10^4	5.0
0.24-0.6	0.295	5.5×10^4	3.0	6.4×10^4	5.1

FERMILAB E1039 EXPERIMENT

(Un)Polarized Drell-Yan Experiments

Experiment	Particles	Energy (GeV)	x_b or x_t	Luminosity ($\text{cm}^{-2} \text{s}^{-1}$)		P_b or P_t (f)	rFOM [†]	Timeline
COMPASS (CERN)	$\pi^\pm + p^\uparrow$	160 GeV $\sqrt{s} = 17$	$x_t = 0.2 - 0.3$	2×10^{33}	0.14	$P_t = 90\%$ $f = 0.22$	1.1×10^{-3}	2014, 2018
PANDA (GSI)	$p + p^\uparrow$	15 GeV $\sqrt{s} = 5.5$	$x_t = 0.2 - 0.4$	2×10^{32}	0.07	$P_t = 90\%$ $f = 0.22$	1.1×10^{-4}	>2018
PAX (GSI)	$p^\uparrow + p$	collider $\sqrt{s} = 14$	$x_b = 0.1 - 0.9$	2×10^{30}	0.06	$P_b = 90\%$	2.3×10^{-5}	>2020?
NICA (JINR)	$p^\uparrow + p$	collider $\sqrt{s} = 26$	$x_b = 0.1 - 0.8$	1×10^{31}	0.04	$P_b = 70\%$	6.8×10^{-5}	>2018
PHENIX (RHIC)	$p^\uparrow + p$	collider $\sqrt{s} = 500$	$x_b = 0.05 - 0.1$	2×10^{32}	0.06	$P_b = 60\%$	3.6×10^{-4}	>2018
SeaQuest (FNAL: E-906)	$p + p$	120 GeV $\sqrt{s} = 15$	$x_b = 0.35 - 0.9$ $x_t = 0.1 - 0.45$	3.4×10^{35}	---	---	---	2012 - 2015
Pol tgt DY [‡] (FNAL: E-1039)	$p + p^\uparrow$	120 GeV $\sqrt{s} = 15$	$x_t = 0.1 - 0.45$	4.4×10^{35}	0 - 0.2*	$P_t = 80\%$ $f = 0.176$	0.13	2016
Pol beam DY [§] (FNAL: E-1027)	$p^\uparrow + p$	120 GeV $\sqrt{s} = 15$	$x_b = 0.35 - 0.9$	2×10^{35}	0.04	$P_b = 60\%$	1	2018
[‡] 8 cm NH ₃ target [§] $L = 1 \times 10^{36} \text{ cm}^{-2} \text{ s}^{-1}$ (LH ₂ tgt limited) / $L = 2 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ (10% of MI beam limited) [*] not constrained by SIDIS data / [†] rFOM = relative lumi * P ² * f ² wrt E-1027 (f=1 for pol p beams)								

W. Lorenzon (U-Michigan)

STATUS and MAJOR ACCOMPLISHMENTS

The experiment is fully funded by DOE: stage-2 approval May, 2018

- polarized target ($>90\%$ of p polarization)
 - rebuild superconducting magnet, rotate coils
 - modify 1K evaporative refrigerator

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 - modify 1K evaporative refrigerator
- new NMR system
 - replacing 30 years-old Liverpool Q-meter
- LHe liquefier for helium recirculation
- major modifications in Experimental Hall
 - new shielding design, beam collimators upstream
 - move target 200cm upstream, target cave, cryo-platform
- inherit spectrometer from SeaQuest E906
 - dedicated trigger, online vertex reconstruction (res. 30 cm)

STATUS and MAJOR ACCOMPLISHMENTS

Current timeline:

E1039 COLLABORATION

We are inviting you to E1039 collaboration

expertise, manpower, ...

Contact Spokespersons: Kun Liu (liuk@fnal.gov) - LANL
Dustin Keller (dustin@jlab.org) - UVA

Please talk to me after the talk: myurov@lanl.gov

Learn more about E1039:

<https://wiki.shanti.virginia.edu/display/SeaQuest/>

THANK YOU

RECENT SIVERS EXTRACTION

Anselmino, M. et. al, [https://doi.org/10.1007/JHEP04\(2017\)046](https://doi.org/10.1007/JHEP04(2017)046)