E1039/SpinQuest Polarized Drell-Yan Experiment at Fermilab

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$$\alpha_s(Q^2) = \frac{1}{\frac{33-2N_f}{12\pi} \ln\left(\frac{Q^2}{\Lambda^2}\right)}$$

Motivation

1. quarks & gluons contribute to single nucleon's **mass**, **spin (this talk)** and **size**
2. quarks & gluons contribute to nuclear binding energy

Measured contributions to the origin of proton spin

Nucleon spin puzzle has remained since 1988...

Predicted contributions to the origin of proton spin

Precision in $\Delta\Sigma$ and $\Delta g \rightarrow$ A clear idea
Of the magnitude of $L_Q + L_G$

orbital motion of quarks & gluons (this talk)

$$L_{Q,G} = \frac{1}{2} - (\Delta\Sigma + \Delta G)$$

**EIC
prediction**

**E1039
prediction**

“Transverse” approaches of **sea** quarks’ orbital motions

y-polarized nucleon moves along Z

OAM of sea quarks & gluons (this talk)

$$\propto \vec{S}_1 \cdot (\vec{p}_1 \times \vec{k}_q)$$

1. **intrinsic** orbital motion of **sea** quarks on transverse plane
2. **spin-orbital correlations** between polarized single nucleon's spin, S^N and non-polarized **sea** quarks', defined as $L_q = b_q^T \times K_q^L$ (non-zero b_q^T implies non-zero L_q and K_q^T besides, $K_q^L = x_{BJ} * P_Z^N$) orbital angular momentum, aka: OAM
3. transverse motion (L_q and K_q^T) of quarks is **flavor-dependent** (both in valence and **sea** quarks?)
4. accessible in Drell-Yan

Sivers asymmetry measurements in Drell-Yan

Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \rightarrow DX, BX$ unpolarized proton beam transversally polarized NH3 target	$\vec{q}\vec{q} \rightarrow c\bar{c}, b\bar{b}$	Δg
$\vec{p}\vec{p} \rightarrow \mu^+\mu^- X$ (Drell-Yan) unpolarized proton beam transversally polarized NH3 target	$\vec{q}\vec{\bar{q}} \rightarrow \gamma^* \rightarrow \mu^+\mu^-$	$\Delta q, \Delta \bar{q}$

The Drell-Yan process:

$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{9x_b x_t s} \sum_q e_q^2 [\bar{q}_t(x_t)q_b(x_b) + \cancel{q_t(x_t)\bar{q}_b(x_b)}]$$

small

$\bar{q}_t(x_t)$: target sea quark at low/intermediate x

$q_b(x_b)$: beam valence quark at high x

Sivers asymmetry measurements in Drell-Yan

Polarized Drell-Yan

$$A_N = \frac{\sigma_L^\uparrow - \sigma_R^\uparrow}{\sigma_L^\uparrow + \sigma_R^\uparrow} = \frac{N_L - N_R}{N_L + N_R}$$

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

$\propto \vec{S}_1 \cdot (\vec{p}_1 \times \vec{k}_q)$

non-zero asymmetry measurements imply non-zero Sivers, leading to non-zero OAM contribution of sea quarks to the origin of proton's spin

E1039/SpinQuest (fixed-target experiment) is designed to get A_N in order to shed light on OAM contribution from sea quarks to the origin of proton's spin!

E1039/SpinQuest Collaboration

Sivers Asymmetries in Drell-Yan

Spectrometer for Sivers asymmetry measurements

Reconstructed final-states through multi-wire proportional/drift chambers (simulation vs. E906 data)

Chamber readout principle

signal response time
10 ns – 10 μ s

card attached directly to DC

UPenn-CDF ASDQ cards

amplified

Disc

Readout test benches in WH14E/NM4@Fermilab

Single drift cell

convert drift time to drift distance in use for hit recognition and track reconstruction as well

Read out

1010011

Taiwan TDCs

TDC

time-to-digital converter

DAQ Set-up

Taiwan TDCs

Projected Drell-Yan Transverse Single Spin Asymmetry

$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp, \bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)} A_{\text{meas}} = \overset{\text{dilution factor}}{f} \cdot \overset{\text{target polarization}}{P_T} \cdot A_{\text{phy}}$$

$$\Delta A = \frac{1}{f} \frac{1}{P} \frac{1}{\sqrt{N^+ + N^-}}$$

X_{targ}	$\langle X_{\text{targ}} \rangle$	$\text{NH}_3 (p^\uparrow)$		$\text{ND}_3 (d^\uparrow)$		$n^\uparrow$
		N	ΔA (%)	N	ΔA (%)	ΔA (%)
0.10 - 0.16	0.139	5.0×10^4	3.2	5.8×10^4	4.3	5.4
0.16 - 0.19	0.175	4.5×10^4	3.3	5.2×10^4	4.6	5.7
0.19 - 0.24	0.213	5.7×10^4	2.9	6.6×10^4	4.1	5.0
0.24 - 0.60	0.295	5.5×10^4	3.0	6.4×10^4	4.1	5.1

Current & Future Exp.

E1039 Status & Plan

- DOE approval, March 2018
- E906 decommissioned 6/2018
- E1039 target shielding in progress
- Beam collimator in progress
- Polarized target to be installed by fall of 2019
- Fermilab Stage-2 approval, May 2018
- Target installation in progress 2019
- E1039 commissioning starts in late 2019
- Run for 2+ years, 2019-2021+