Fermilab SpinQuest/E1039 experiment with Transversely Polarized Target

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E1039 SpinQuest collaboration

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QUEST for PROTON SPIN ORIGIN

- 1987 EMC polarized DIS measurements:
contributions of spins of quarks and anti-quarks to the proton spin are small
- broad world-wide program to resolve the
problem of the nucleon spin composition
- In spite of significant experimental and theoretical advances
basic problem remains after 30 years of research
- components contributing to proton spin

$$\Delta\Sigma \quad \Delta G \quad L_q \quad L_g$$

WHY ARE WE DOING E1039?

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

○ importance of sea quarks

- account for spin of quarks, anti-quarks and gluons - still missing about half the picture
- sea quark OAM could be a major part of missing spin

○ contribution of OAM of sea quarks remains poorly constrained

○ important to understand theoretically and experimentally

○ SpinQuest/E1039 will explore properties of the nucleon's spin composition by investigating correlation of the light antiquarks motion relative to the nucleon spin

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

HINTS OF NON-ZERO OAM

○ sea quarks flavor asymmetry observation

E866/NuSea: enhanced $\bar{d}/\bar{u}$

E906/SeaQuest: $\sigma_{pd}/2\sigma_{pp}$

○ 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 Dependent distribution functions (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
- if sea-quark Sivers asymmetry is non-zero, then sea quarks have non-zero 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
 - the only high statistics 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

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E1039 EXPERIMENT

FERMILAB E1039 EXPERIMENT

asymmetry estimates (E1039 proposal)

more recent calculations

- 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

○ FNAL 120GeV proton beam

- $\sqrt{S} = 15.5\text{GeV}$
- 5×10^{12} p/spill; 4.3 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
 $E_{\text{beam}} = 120\text{ GeV}$

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

STATUS and MILESTONES

**The experiment is fully funded by DOE,
Stage-2 approval: 05/2018.**

STATUS and MILESTONES

- major modifications in experimental hall
 - beamline: new collimator
 - new radiation shielding design
 - new cryo platform for polarized target infrastructure
 - polarized target cave: new location 300cm upstream of FMAG

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○ special thanks to Fermilab support

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NM3: looking downstream

NM4: looking upstream

STATUS and MILESTONES

- new polarized target construction: LANL and UVA effort
 - rebuild magnet; change field direction
 - modify 1K refrigerator and insert
 - new pump set; high cooling capacity
 - new high power microwave source

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○ new NMR system

- replacing Liverpool Q-meter
- double wide VME module
- electronic LCR and phase tune
- cold NMR

new Q-meter
boards

crate
controller

new LANL NMR setup

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- He liquefier for liquid helium recirculation
 - constructed by "Quantum technologies"
 - ~200L/day capacity
- inherit spectrometer from SeaQuest E906 experiment
 - dedicated vertex trigger
 - collaboration wide effort to prepare detectors/DAQ for experiment

STATUS and MILESTONES

Current timeline:

SpinQuest/E1039 COLLABORATION

Contact Spokespersons:

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Learn more about SpinQuest/E1039:
<https://spinquest.fnal.gov/>

THANK YOU