- **SpinQuest** Target : Arthur's talk
- **SeaQuest** Spectrometer : Me

E1039/SpinQuest Polarized Drell-Yan Experiment at Fermilab

Chun-Min Jen
on behalf of the SpinQuest (E1039) Collaboration

Fermilab Dimuon Spectrometer: Fixed Target Drell-Yan

(E605 / 772 / 789 / 866 / 906)

1) Fermilab E772 (proposed in 1986 and completed in 1988)

"Nuclear Dependence of Drell-Yan and Quarkonium Production"

2) Fermilab E789 (proposed in 1989 and completed in 1991)

"Search for Two-Body Decays of Heavy Quark Mesons"

3) Fermilab E866 (proposed in 1993 and completed in 1996)

"Determination of $\bar{d}/\bar{u}$ Ratio of the Proton via Drell-Yan"

4) Fermilab E906 (proposed in 1999, ~~will run in 2010-2013~~)

"Drell-Yan with the FNAL Main Injector" **decommission in spring 2018**

Fermilab E1039 (proposed in 2013, will run in 2019-2021)

Now, it's commissioning (fall 2018...)

E1039 Collaboration

Rich Physics Extracted from First Polarized Drell-Yan at FNAL

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

- SpinQuest opportunities:
 - ★ Sea Quark Sivers (low- X , < 0.5)
 - ★ Gluon Sivers (high- X , > 0.5)
 - ★ Transversity
 - ★ open charm TSSA:
 - charm vs. anti-charm
 - ★ Dark photon and heavy photon

Sea Quark Sivers from global fits

Precise SpinQuest data helps further constrain sea quark Sivers!
Systematics uncertainties are critical in high-precision measurements!
(See Arthur's talk)

- SpinQuest data is through QED process w/o:
 - QCD final-state effect
 - fragmentation function of final-state hadrons

Kang et al, 1401.5078

three PDFs used to describe K^q_T and/or $S^{n/q}_T$

three transversal quantities are

- (1) nucleon's transversal spin (S^n_T);
- (2) quark's transversal spin (S^q_T);
- (3) quark's transversal momentum (K^q_T)

three PDFs are

- (1) + (2) : Transversity
- (1) + (3) : Sivers function
- (2) + (3) : Boer-Mulders function

four types of Drell-Yen experiments at FNAL are as follows:

- polarized-beam & polarized-target Drell-Yan : Transversity (E10xx)
- **polarized-target & unpolarized-beam Drell-Yan : Sivers function (E1039)**
- polarized-beam & unpolarized-target Drell-Yan: Sivers function (E1027)
- unpolarized Drell-Yan : Boer-Mulders function (E605, E772, E789, E866, E906)

three transversal quantities are

(1) nucleon's transversal spin (S_T^n);

(2) quark's transversal spin (S_T^q);

(3) quark's transversal momentum (K_T^q) - “off-diagonal” terms

→ Nucleon Spin
→ Quark Spin

		Quark polarization		
		Un-Polarized	Longitudinally Polarized	Transversely Polarized
Nucleon Polarization	U	$f_1 =$ $UU=T_{\text{even}}$		$h_1^\perp =$ - Boer-Mulder $TU=T_{\text{odd}}$
	L		$g_1 =$ - Helicity $LT=T_{\text{even}}$	$h_{1L}^\perp =$ - $TL=T_{\text{even}}$
	T	$f_{1T}^\perp =$ - Sivers $UT=T_{\text{odd}}$	$g_{1T}^\perp =$ - $LT=T_{\text{even}}$	$h_{1T} =$ - Transversity $TT=T_{\text{even}}$ $h_{1T}^\perp =$ - Pretzelosity

More TSSA Measurements (II)

TSSA: **T**ransversal **S**ingle **S**pin **A**symmetry

Transverse Single Spin Asymmetries A_N

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

Theory Expectation:

Small asymmetries at high energies

(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{\sqrt{s}}$$

$A_N \sim \mathcal{O}(10^{-4})$ theory

Experiments:

ZGS, AGS, FERMILAB to RHIC

$pp^\uparrow \rightarrow \pi + X$ $A_N \sim \mathcal{O}(10^{-1})$ observed

$\sqrt{s} = 5 \sim 500$ GeV

large TSSAs up to 40% are observed in light hadron-production over a wide range of beam energies ($10-10^4$) at forward $X_F (>0.5)$ region, where fractional momentum of transversally polarized nucleon is within 0.1 and 0.5.

More TSSA Measurements (II)

TSSA: Transversal Single Spin Asymmetry

Theoretically,

$$A_N \propto \frac{m_q}{\sqrt{S}}$$

Transverse SSA's
from low to high energies

what does m_q mean here?

fixed target

Non-Perturbative cross section $\longrightarrow$ Perturbative cross section

asymptotic freedom $\longrightarrow$ new physics beyond SM

Two Possible TSSA Mechanisms

three transversal quantities are

- (1) nucleon's transversal spin (S^n_T);
- (2) quark's transversal spin (S^q_T);
- (3) quark's transversal momentum (K^q_T)

(1) + (3) PRD41 (1990) 83; 43 (1991) 261

three PDFs are

- (1) + (2) : Transversity
- (1) + (3) : Sivers function
- (2) + (3) : Boer-Mulders function

(1) + (2) Nucl. Phys. B396 (1993) 161

TSSA measurement in polarized DY

Theory: K_T vs Collinear Factorization

- Tran. Mom. Dep. Funs

- Sivvers Fun
- Collins Fun

$$\frac{d^3\sigma^\dagger(pp^\dagger \rightarrow h + X)}{dx_1 dx_2 dz} \propto q_i^\dagger(x_1, k_{q,T}) \cdot q_j(x_2) \times \frac{d^3\hat{\sigma}^\dagger(q_i q_j \rightarrow q_k q_l)}{dx_1 dx_2} \times FF_{q_{k,l}}(z, p_{h,T})$$

- Twist-3 collinear

- Quark-gluon correl.
- Gluon-gluon correl.

SpinQuest also sheds light on gluon Sivvers!

- field: 5T @ 1K
- elliptical: 1.9 cm x 2.1 cm (x,y), l:7.9 cm (z)
- ρ : 0.87 g/cm³ NH₃
- packing fraction: 0.6
- dilution factor : 0.176
- Polarization <80%>
- IL: 8.6%
- 3 active cells, 1 empty
- Helium consumption 100 l/day

SeaQuest Spectrometer

10% of available beam to SeaQuest
/ 90% to neutrino program

- $2.7 \cdot 10^{12}$ p/spill, duty cycle: one 4s spill/minute
- kinematic range $4 < M < 9$ GeV
- luminosity: $3 \cdot 10^{35}$ /cm²/s (NH₃)
- $\sqrt{s} = 15$ GeV
- move **polarized target** ~2m upstream
→ improves target-dump separation
→ moves acceptance to lower x_2

$$\mathcal{L}_{int} = 1.82 \cdot 10^{42} / \text{cm}^2 \text{ NH}_3 \text{ for 2 years}$$

Ref: Andi Klein (LANL)

2018 fall - 2019 summer

E1039 SpinQuest (No)-beam Commissioning

1. installation is now ongoing;
2. expect initial **BEAM** commissioning in this summer;
3. expect brief commissioning in fall and production data taking by the end of this year;
4. 2 year of data taking (Dec. 2019 - Dec. 2021)