Dimuon Production – Recent Results and Future Prospect

Jen-Chieh Peng

University of Illinois at Urbana-Champaign



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Complimentality between DIS and Drell-Yan



Both DIS and Drell-Yan process are tools to probe the quark and antiquark structure in hadrons (factorization, universality)

Fermilab Dimuon Experiments (E772 / 789 / 866 / 906 /1039)



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 d / \overline{u} Ratio of the Proton via Drell-Yan" 4) Fermilab E906 / SeaQuest (proposed in 1999, completed in 7/2017) "Drell-Yan with the FNAL Main Injector" 5) Fermilab E1039 /SpinQuest (proposed in 2016, scheduled 2021) "Drell -Yan with a Transversly Polarized Target at SeaQuest"

Disentangling Explanations of Deep-Inelastic Lepton-Nucleus Scattering by Lepton-Pair Production

R. P. Bickerstaff, M. C. Birse, and G. A. Miller

Institute for Nuclear Theory, Department of Physics, University of Washington, Seattle, Washington 98195 (Received 18 June 1984)

Fe/D Ratio in DIS

Fe/D Ratio in Drell-Yan



FIG. 1. Ratio of the structure function per nucleon, $F_2^A(x)/A$, for Fe to that for D. The experimental points assume $R = \sigma_L/\sigma_T$ is constant.



FIG. 2. Ratio of the Drell-Yan differential cross section for Fe to that for D, as a function of x_2 , at $x_1 = 0.1$.



- Nuclear effects are relatively small for Drell-Yan, but much larger for J/ψ and Y resonances
- Nuclear effects for Drell-Yan have some p_T and x_F dependencies



Nuclear Dependence of Dimuon Production at 800 GeV

- No evidence of enhancement of pion contents in nuclei!
- A surprisingly small difference between p+A and p+d Drell-Yan.
- (p+d) / (p+p) ratio was not measured.



Origins of $\overline{u}(x) \neq \overline{d}(x)$?



Theory: Thomas, Miller, Kumano, Ma, Londergan, Henley, Speth, Hwang, Melnitchouk, Liu, Cheng/Li, Soffer, Buccella, Bourrely etc. (For reviews, see Speth and Thomas (1997), Kumano (hep-ph/9702367), Garvey and Peng (nucl-ex/0109010))

Theses models also have implications on

- asymmetry between s(x) and $\overline{s}(x)$
- flavor structure of the polarized sea

Statistical model naturally explains this sea-quark flavor asymmetry

Soffer's slide at the ECT* Workshop on "Flavor Structure of the Nucleon Sea" Trento, July 1-5, 2013

- $\bar{d}(x) > \bar{u}(x)$, flavor symmetry breaking expected from Pauli exclusion principle. This was already confirmed by the violation of the Gottfried sum rule (NMC).
- △ $\bar{u}(x) > 0$ and $\Delta \bar{d}(x) < 0$, a PREDICTION from 2002, in agreement with polarized DIS (see below) and will be more precisely checked at RHIC-BNL from W^{\pm} production, already in active running phase (see below).

Note that since $u^-(x) \sim d^-(x)$, it follows that $\bar{u}^+(x) \sim \bar{d}^+(x)$, so we have

$$\Delta \bar{u}(x) - \Delta \bar{d}(x) \sim \bar{d}(x) - \bar{u}(x) ,$$

i.e. the flavor symmetry breaking is almost the same for unpolarized and polarized distributions ($\Delta \bar{u}$ and $\Delta \bar{d}$ contribute to about 10% to the Bjorken sum rule).

- The antiquark's flavor structure is related to quark's flavor structure
- The antiquark's spin structure is related to quark's spin structure

Soffer' slide at the ECT* Workshop on "Flavor Structure of the Nucleon Sea" Trento, July 1-5, 2013



SeaQuest Drell-Yan Experiment at Fermilab

(Unpolarized Drell-Yan using 120 GeV proton beam, Reimer, Geesaman are co-spokesmen)





Main goal : Measure $\overline{d} / \overline{u}$ flavor asymmetry up to $x \approx 0.45$

- Commission run took place in February April 2012
- 3-year production run in 2014-2017

Two methods to determine the (p+d)/(p+p)Drell-Yan cross section ratio



a) Fitting the mass spectrum

- Determine the size of the accidental background from a fit to the mass distribution
- Accidental background spectrum shape is obtained from mixing single-muon events

Jason Dove DIS 2019

Two methods to determine the (p+d)/(p+p)Drell-Yan cross section ratio

b) Extrapolating to zero intensity



 Extrapolating the (p+d)/(p+p) normalized Drell-Yan yields ratio to zero intensity to remove rate dependence

• The intercept gives the cross section ratio

Jason Dove DIS 2019

E906 result presented at the DIS 2019 (April 8-12) (talk by E906 graduate student Jason Dove)



E866 versus E906 and BS15

JS

Jacques SOFFER <jacques.soffer@gmail.com>

Wed 4/17/2019 3:18 AM

Peng, Jen-Chieh; Dove, Jason Alan; BOURRELY <crv.bourrely@orange.fr> >>



ratioenerg120-800.eps

Dear Jen-Chieh and Jason,

Thank you for sending the slides of the nice talk given at DIS19.

For your information we send you our predictions using BS15 (C. Bourrely and J. Soffer,

NPA941, 307 (2015)). We look forward to see the extraction of the ratio dbar/ubar in the high-x region.

Please don't hesitate to send us your comments/questions

Best regards,

Jacques Jacques SOFFER <u>www.qcdspinphysics.com</u>



- The E906 result is in excellent agreement with the prediction of the statistical model (Thank you, Jacques)
- The E906 result was accepted for publication in "Nature" $\frac{16}{16}$

How about the $(p+d)/(p+p) J/\Psi$ cross section ratio ?

- Drell-Yan is an electromagnetic interaction
 - Sensitive to the quark and antiquark distribution in the nucleon
 - The p+d/p+p cross section ratio can provide information on the $\overline{d}/\overline{u}$ asymmetry
- J/ψ is produced via strong interaction
 - Sensitive to both quark and antiquark distribution as well as gluon distribution
 - Provide information complementary to Drell-Yan data

J/Ψ production mechanisms

- Still not fully understood
- Main contributions are from $q\overline{q}$ annihilation and gg fusion
- Relative importance between the $q\overline{q}$ annihilation and gg fusion depends on the kinematice of J/Ψ



Extracting J/ψ yield from dimuon spectrum



DNP-2020 talk by Ching Him Leung (UIUC)

- Use Monte Carlo to simulate signal events $(J/\psi, \psi', DY)$
- Use mixed singletrack events to simulate accidental background
- By fitting the mass spectrum, we obtain the J/ψ yield for individual targets

J/ψ and Drell-Yan cross section ratios vs x_T



DNP-2020 talk by Ching Him Leung (UIUC)

- J/ψ ratio is closer to 1 compared to Drell-Yan
 - Contribution from gluon fusion in J/ψ production
 - The J/ψ data is at a region where $\overline{d}/\overline{u}$ asymmetry is small
- The overall trend for both J/ψ and Drell-Yan are in reasonable agreement with calculation

How about the (p+A) / (p+d)Drell-Yan cross section ratio ?



- Extend the previous measurements to somewhat larger *x*
- Check the nuclear effect on the transverse momentum distributions

SEAQUEST VS E772 ON X_T A-DEPENDENCE



- No enhancement seen as in the case of a pion excess model!
- EMC like behavior is displayed but results are consistent with 1
- Basically in agreement with E772 results in the overlap region

DNP-2019 talk by Arun Tadepalli (Rutgers)

SEAQUEST VS E772 ON P_T A-DEPENDENCE





- Ratio consistent with 1 for C/D
- Drop in the ratio in low pT region and a slight enhancement in the high pT region observed for Fe/D
- More prominent broadening in the case of W/D

APS-2020 talk by Arun Tadepalli (JLab)

E1039 experiment with polarized target

• 120 GeV proton beam from Main Injector

- Improved focusing
- ≻ In development at Fermilab

• Polarized proton/deuteron (NH₃/ND3) target

*γ**→μμ

Co-spokesperson: Dustin Keller, Kun Liu

- ➤ In development at LANL and UVa
- > Modification to target shielding by FNAL
- Measure Sivers asymmetry for ubar and dbar

Existing dimuon spectrometer

- Existing E906 spectrometer
- Collaboration

FNAL MI beam



E1039 can extract sea-quark transversity in proton

E1039 / SpinQuest could lead to new measurement of sea-quark transversity distributions in Drell-Yan

SpinQuest data-taking is expected to begin in late 2021

Exclusive Drell-Yan measurements at J-PARC?

- Exclusive Drell-Yan with meson and antiproton beams are the time-like processes complementary to the deeply virtual meson production at JLab, HERMES and COMPASS
- Exclusive Drell-Yan with meson beam at J-PARC will also complement the program at FAIR using antiproton beam

Takahiro Sawada, Wen-Chen Chang, Shunzo Kumano, Jen-Chieh Peng, Shinya Sawada, Kazuhiro Tanaka, Phys. Rev. D93 (2016) 114034

DEMP versus exclusive Drell-Yan

$$\gamma^* + N \to \pi + N'$$

Deep Exclusive Meson Production

$$\pi + N \to \gamma^* + N'$$

Exclusive Drell-Yan







time-like photon

J-PARC High-momentum Beam Line (Hi-P BL)

S. Sawada, Pacific Spin 2019



•28

Exclusive Drell-Yan measurement in J-PARC E50 Spectrometer



Kinematic regions of GPDs explored by space-like and time-like processes



JLAB, HERMES, COMPASS → Space-like approach
J-PARC → Time-like approach

Summary

- New results are becoming available for the dimuon production (Drell-Yan and J/Psi) SeaQuest experiment at Fermilab
- New Fermilab experiment, SpinQuest, with polarized target is expected to provide information complementary to COMPASS polarized Drell-Yan program.
- Exclusive reactions using meson beams at J-PARC complement Jlab, COMPASS, and FAIR physics program.
- More interesting physics results to come ...