Flavor Asymmetry in Light Quark Sea and Quark Energy Loss at Fermilab E906/SeaQuest Experiment

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XXIII International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2015)
Dallas, TX, April 27 - May 1, 2015
E906/SeaQuest experiment at Fermilab

Aimed at measuring dimuon production in Drell-Yan process and charmonium decay

**Target system**
- Liquid H and D
- Solid C, Fe, W

**Beam**
- 120 GeV proton from Main Injector
  - 19ns RF, 5s spill, $1 \times 10^{13}$ protons per spill

**Focusing magnet and solid iron dump**
- $\Delta p_t = 2.9$ GeV

**Spectrometer magnet**
- $\Delta p_t = 0.4$ GeV

**Tracking detectors**
- Drift chambers and hodoscope scintillators

**Absorber wall and proportional tube based Muon ID**

25 m.
E906/SeaQuest Collaboration

2009 @ Los Alamos

2013 @ Tokyo Tech

Strong flavor asymmetry in the sea.

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Projected 3.4 $\times 10^{18}$ POT

E866

NAS1

MRS12

CTEQ4m

CTEQ6

2009 @ Los Alamos
E906 kinematic coverage

The Drell-Yan process:

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

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

\(q_b(x_b)\): beam valence quark at high x
DY vs. DIS on sea quark sensitivity
Flavor asymmetry in light quark sea

- Assuming charge symmetry, ignoring nuclear effects of deuterium and heavy quark contributions:

\[
\frac{\sigma^{pd}}{2\sigma^{pp}} \bigg|_{x_1 \gg x_2} \approx \frac{1}{2} \left[ 1 + \frac{\bar{d}(x_2)}{\bar{u}(x_2)} \right].
\]

- Naively we would expect flavor symmetry between \(\bar{u}\) and \(\bar{d}\)

- E866/NuSea experiment reveals a striking asymmetry in the sea distributions at moderate \(x\)

- Caused by virtual pions?

- Important constraints on light sea polarization

- No models until recently (Peng et al, PLB 736 2014, 411) could incorporate the sign change at \(x > 0.25\)
Measurement of $\bar{d}/\bar{u}$ at E906/SeaQuest

- E906 is based on 120 GeV proton beam from Main Injector compared with 800 GeV beam of E866 → much lower $\sqrt{s}$

- Drell-Yan cross section scales as $1/s$
- $J/\psi$ cross section scales as $s$

50x improvement of precision

- Common $x$ coverage with E866 and E772, and extend to higher region
Partonic energy loss in Drell-Yan process

- Fundamental probe to study matter properties
- Accessing energy loss from hard scattering in hot and dense medium in heavy ion physics:
  - nuclear modification $R_{AA} \ll 1$ at high $p_T$
  - very model-dependent
- Drell-Yan process provides a clean baseline calibration since there is only minimal final state interactions

$\hat{q} = \frac{\mu^2}{\lambda}$

$\omega = xE$

$\omega = (1-x)E$

$\to \langle \hat{q} \rangle = 2 \sim 20 \text{ GeV}^2 / \text{fm}$
Early data from E866 @ Fermilab

- **Energy loss vs. shadowing**
  - Correction must be made for shadowing effects
  - NO partonic energy loss if all effects from shadowing
    - Vasiliev et al., PRL 83 (1999)
  - Significant parton energy loss, \( \sim 1.2 \text{ GeV/fm} \) if all from energy loss
    - Johnson et al., PRC 65 025203 (2002)

Both yield 20~30% effects in \( R_{PA} \)
E906 Drell-Yan dimuon acceptance

- Parton initial energy: 30 - 120 GeV (relevant to RHIC and LHC parton energy)
- Direct test on various models:
  - Gavin and Milana: $\Delta x_1 = -\kappa_1 x_1 A^{\frac{1}{3}}$
  - Brodsky and Hoyer: $\Delta x_1 = -\frac{\kappa_2}{A^{\frac{1}{3}}}$
  - Baier et al.
- Sea quark $x = 0.1 \sim 0.3$
- Minimal shadowing
- $1/s$ enhanced $dE/dx$ effect

First unambiguous determination of $dE/dx$ in CNM
Dark photon search

Dark photon (A'):
• gauge boson of the U(1) extension to SM
• dark photon - SM fermion coupling strength $\alpha' = \varepsilon^2 \alpha$

- Sensitive to $10^{-7} < \varepsilon < 10^{-5}$, 220 MeV < $m_{A'}$ < 550 MeV
- Primary limiting factor:
  - displaced vertex
  - detector acceptance at large angle
- New proposals under discussion to extend our sensitivity region
Timeline and milestones of SeaQuest

- **First proposal**
- **Detector assembled**
- **First proton**!
- **Run-I**
- **Main injector upgrade**
- **Run-II**
- **Run-III**
- **Future upgrades of polarized program**

- **1999**
- **2011**
- **2012**
- **2013**
- **2014**
- **2015**
- **2016**

- **Very preliminary**

- Due to various delays, only a very short 2-month commissioning Run-I was taken in early 2012
- In the longer Run-II, we solved almost all the problems discovered in Run-I
- After a short 2-month accelerator maintenance, we started a 2-yr Run-III
- New station-1 drift chamber will be installed soon to extend the $x_2$ coverage
- Polarized projects (target and/or beam) will take over in summer 2016

Dr. Markus Diefenthaler, Polarized Drell-Yan measurement at Fermilab: The future of the SeaQuest experiment, WG7, Apr. 30
Data from FY 2014 (Run-II)

- Monte Carlo describe data well
- Resolution better than expected
  - $\sigma_M(J/\psi) \sim 180$ MeV, $\sigma_M(DY) \sim 220$ MeV
  - $J/\psi\,\psi'$ separation
  - Cleaner DY sample
- Good target/beam dump separation

- Beam quality worse than expected (instantaneous rate much higher than average)
  - live time of spectrometer greatly reduced by the ‘super’ RF buckets
  - Reconstruction efficiency lower than expected because of the high detector occupancy

- Entire beam interacts upstream of SeaQuest spectrometer
- Pointing resolution very poor along beam axis
- Dominated by random coincidences
E906 preview measurements on $\bar{d}/\bar{u}$

- Only consists of 5% of the total expected statistics
- Well consistent with E866 results at low $x_2$
- Interesting behavior at high $x_2$, with large statistical uncertainties. New larger drift chamber and more statistics will help us pin down this point.
- Current systematic error mainly comes from LD$_2$ impurity and unresolved rate-dependence. We expect final systematic uncertainty to be $\sim$1%
Quark energy loss at E906

- Too early to make any conclusion on p+Fe as limited by the statistics
- A consistently negative slope beyond the shadowing strength is observed in p+W data.
- With 20x more statistics, we will be able to clearly distinguish between:
  ➢ \(-dE \propto A^{1/3}\) (or \(\propto L\))
  ➢ \(-dE \propto A^{2/3}\) (or \(\propto L^2\))
Run-II: 5% of total statistics:
• confirmed the large light sea quark asymmetry at $x_2 \sim 0.15$, while the sign change at $x_2 > 0.3$ still waits for more statistics
• observed a negative slope beyond the extent of shadowing

Ongoing Run-III: ~20x of Run-II statistics

Other ongoing physics analysis:
• EMC effect in Drell-Yan
• Transverse momentum broadening
• Difference between J/Ψ and Ψ’ suppression in pA
• Search for double J/Ψ production
• Search for dark photons
• ...