The E906/SeaQuest Experiment

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E906/SeaQuest experiment at Fermilab

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

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

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

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

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

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

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

25 m
A brief history

- **Run-I**: 2-month commissioning, first J/ψ signal
- **Run-II**: solved almost all the technical problems and substantial improvement in beam quality, *first physics results*
- **Run-III**: 
  - high quality beam
  - new station-1 DC to increase the $x_2$ coverage
- **Polarized projects** (target and/or beam) will take over in summer 2016

Our heartfelt thanks to Accelerator Division for their remarkable work on improving the beam quality
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don't know how to display the graphs and pictures

2009 @ Los Alamos

2013 @ Tokyo Tech
E906 kinematic coverage

The Drell-Yan process:

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

\( q_t(x_t) \): target sea quark at low/intermediate \( x \)

\( q_b(x_b) \): beam valence quark at high \( x \)
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 $x > 0.25$
Quark energy loss in DY

- Fundamental probe to study matter properties, like QGP produced at RHIC and LHC
- Observables result from convolution of initial and final state interactions
- Drell-Yan provides a clean baseline measurement

- Early data from E866
  - Correction must be made for shadowing effects
    • Garvey & Peng PRL 90 (2003)
  - NO partonic energy loss if all effects from shadowing
    • Vasiliev et al., PRL 83 (1999)
  - Significant parton energy loss, ~1.2 GeV/fm if all from energy loss
    • Johnson et al., PRC 65 025203 (2002)

Both yield $20\sim30\%$ effects in $R_{pA}$

Figure 11: Comparison of the average valence and sea quark, and gluon modifications at $Q^2 = 1.69 \text{ GeV}^2$ for Pb nucleus from LO global DGLAP analyses EKS98 [1, 2], EKPS [3], nDS [6], HKN07 [5], and this work EPS09LO.
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:
  - Brodsky and Hoyer:
  - Baier et al:
    \[ \Delta x_1 = -\kappa_1 x_1 A^{1/3} \]
    \[ \Delta x_1 = -\kappa_2 A^{1/3} \]
    \[ \Delta x_1 = -\frac{\kappa_3}{s} A^{2/3} \]
- Sea quark \( x = 0.1 \sim 0.3 \)
- Minimal shadowing
- \( 1/s \) enhanced dE/dx effect

First unambiguous determination of dE/dx in CNM
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 $\propto L^2$)
Summary

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
• Angular distribution of DY and J/ψ produced in beam dump
• Search for dark photons
• ...

Future polarized program
• target: sea quark Sivers asymmetry in DY
• beam: valence quark Sivers asymmetry in DY
Backup slides
EMC effect in DY

SeaQuest PREVIEW

\sim 5\% \text{ of anticipated data}