Status of Drell-Yan Experiment by SeaQuest at FNAL

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International Workshop on the Quark-Gluon Structure of the Nucleon @ 東工大
Today’s Menu

What we might learn today:

- Light antiquark flavour Asymmetry in the Proton
- Past Measurements
- The Drell-Yan Process as a tool to probe this Flavour Asymmetry
- The SeaQuest-Experiment and the 120 GeV beam
- Some commissioning results
- Conclusion and outlook
What is the Proton?

- Three “Valence” quarks
  - 2 “up” quarks (q = $+\frac{2}{3}$)
  - 1 “down” quark (q = $-\frac{1}{3}$)
- Bound together by gluons
- Gluons can split into quark-antiquark pairs (similar to the photon splitting into an electron-positron pair)
- The Proton “Sea” is formed of quarks and antiquarks
What’s the distribution of sea quarks?

In the nucleon:
- Sea and gluons are important:
  - 98% of mass; 60% of momentum at $Q^2 = 2\, \text{GeV}^2$
- Not just three valence quarks and QCD. Shown by E866/NuSea d-bar/u-bar data
- What are the origins of the sea?
- Significant part of LHC beam.

In nuclei:
- The nucleus is not just protons and neutrons
- What is the difference?
  - Bound system
  - Virtual mesons affects antiquarks distributions

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\[ S_G = \frac{1}{3} \left( F_2^p - F_2^n \right) \frac{dx}{x} \]

\[ = \frac{1}{3} + \int_0^1 \frac{2}{3} \left[ \bar{u} - \bar{d} \right] dx \]

\[ = \frac{1}{3} \]

\[ u = d \]
\[ S_G = 0.235 \pm 0.026 \]

Nuclear shadowing (double scattering of virtual photon from both nucleons in deuteron) \( \sim 4\text{-}10\% \) effect on Gottfried sum

\[ \rightarrow \text{disagreement with naive calculation of GSR remains} \]
- Naïve Assumption: \( \bar{d}(x) = \bar{u}(x) \)

- NMC (Gottfried Sum Rule)
  \[
  \int_0^1 \left[ \bar{d}(x) - \bar{u}(x) \right] dx \neq 0
  \]
- **Naïve Assumption:**
  \[
  \bar{d}(x) = \bar{u}(x)
  \]

- **NMC (Gottfried Sum Rule)**
  \[
  \int_0^1 \left[ \bar{d}(x) - \bar{u}(x) \right] \, dx \neq 0
  \]

- **NA51 (Drell-Yan)**
  \[
  \bar{d} > \bar{u} \text{ at } x = 0.18
  \]
Naïve Assumption: 
\[ \bar{d}(x) = \bar{u}(x) \]

NMC (Gottfried Sum Rule) 
\[ \int_0^1 \left[ \bar{d}(x) - \bar{u}(x) \right] \, dx \neq 0 \]

NA51 (Drell-Yan) 
\[ \bar{d} > \bar{u} \text{ at } x = 0.18 \]

E866/NuSea (Drell-Yan) 
\[ \frac{\bar{d}(x)}{\bar{u}(x)} \text{ for } 0.015 \leq x \leq 0.35 \]

Knowledge of distributions is data driven
- Sea quark distributions are difficult for Lattice QCD

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There is a gluon splitting component which is symmetric
\[ \bar{d}(x) = \bar{u}(x) = \bar{q}(x) \]

\[ \bar{d} - \bar{u} \]

- Symmetric sea via pair production from gluons subtracts off
- No Gluon contribution at 1st order in \( \alpha_s \)
- Nonperturbative models are motivated by the observed difference

A proton with 3 valence quarks plus glue **cannot be right at any scale!!**
- Meson Cloud in the nucleon
- Sullivan process in DIS
\[ |p> = |p_0> + \alpha |N\pi> + \beta |\Delta\pi> + \ldots \]

- Chiral Models
- Interaction btw. Goldstone Bosons and valence quarks
\[ |u> \rightarrow |d\pi^+> \text{ and } |d> \rightarrow |d\pi^-> \]

Perturbative sea apparently dilutes meson cloud effects at large-x
All non-perturbative models predict large asymmetries at high $x$.

Are there more gluons and therefore symmetric anti-quarks at higher $x$?

Does some mechanism like instantons have an unexpected $x$ dependence? (What is the expected $x$ dependence for instantons in the first place?)
Detector acceptance chooses $x_{\text{target}}$ and $x_{\text{beam}}$.

- Fixed target -> high $x_F = x_{\text{beam}} - x_{\text{target}}$
- Valence Beam quarks at high-$x$.
- Sea Target quarks at low/intermediate-$x$.

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1 x_2} \frac{1}{s} \sum e^2 [\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)]$$

$$\frac{\sigma^{pd}}{2\sigma^{pp}} \bigg|_{x_b \gg x_t} \approx \frac{1}{2} \left[ 1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)} \right]$$
**Fermilab E866/NuSea**
- Data in 1996-1997
  - $^1$H, $^2$H, and nuclear targets
  - 800 GeV proton beam

**Fermilab E906/SeaQuest**
- Commissioning in April & May 2012
  - 2 years of physics data-run beginning in June 2012
  - $^1$H, $^2$H, and nuclear targets
  - 120 GeV proton Beam

- Cross section scales as $1/s$
  - $7x$ that of 800 GeV beam
- Backgrounds, primarily from J/$\psi$ decays scale as $s$
  - $7x$ Luminosity for same detector rate as 800 GeV beam

50x statistics!!

\[
\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi \alpha^2}{9x_1 x_2} \frac{1}{s} \sum_{i} c_i \left[ q_{ti}(x_t) \bar{q}_{bi}(x_b) + \bar{q}_{ti}(x_t) q_{bi}(x_b) \right]
\]
SeaQuest will extend these measurements to $x_B > 0.3$ and reduce statistical uncertainties.

E906 expects systematic uncertainty to remain at approx. 1% in cross section ratio.
The E906-Spectrometer

Solid Iron
Focusing Magnet, Hadron absorber and beam dump

Station 1:
Hodoscope array
MWDC tracking

Mom. Meas.
(KTeV Magnet)

Station 2 and 3:
Hodoscope array
Drift Chamber tracking

Station:
Hodoscope array
Prop tube tracking

Liquid H₂, d₂, and solid targets (Fe, W, C)

25m

Hadron Absorber
(Iron Wall)

Drawing: T. O’Connor and K. Bailey

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• St. 4 Prop Tubes: Homeland Security via Los Alamos
• St. 3 & 4 Hodo PMT’s: E-866, HERMES, KTeV
• St. 1 & 2 Hodoscopes: HERMES
• St. 2 & 3Minus- tracking: E-866
• St. 3Plus: NEW from Tokyo Tech!!!
• St. 2 Support Structure: KTeV
• Target Flasks: E-866
• Cables: KTeV

Station 3: NEW from Tokyo Tech
Station 3-: to be upgraded for Run2

• 2nd Magnet: KTeV Analysis Magnet
• Hadron Absorber: Fermilab Rail Head???
• Solid Fe Magnet Coils: E-866 SM3 Magnet
• Shielding blocks: old beamline (Fermilab Today)
• Solid Fe Magnet Flux Return Iron: E-866 SM12 Magnet
• 53 MHz beam repetition frequency (18.9ns)
• 5 seconds every minute: $2 \times 10^{12}$ protons/sec
  (5 W, $1 \times 10^{13}$ protons/min)
• $5.2 \times 10^{18}$ total protons on target for E906 Physics Runs

18.9 ns RF buckets with 1-2 ns width

• First successful beam delivery to the E906/SeaQuest spectrometer on March 8th 2012!!
• Commissioning run for 2 months in March and April 2012
• From May 2012 Main Injector shut down for high luminosity upgrade
First candidate of a di-muon-pair @ SeaQuest

J/Psi candidate with an invariant mass of ~3.29 GeV
Simple Tracking Scheme

$z_0 = 0 \text{ cm}$

$z_{\text{bend}} = 375 \text{ cm}$

Mom. vs. Kick (Slope difference)

Mom. Resolution (%)

Mass Resolution (GeV)

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• **Very, very preliminary (!!!!):** just clean events are being reconstructed (< 1% of all recorded events)

• Clean = a few hits per tracking station, just a few thousand clean track candidates
Why preliminary?

• Large number of hits on all stations from high instantaneous beam rate
  -> makes track reconstruction difficult for those events (“SPLAT events”)
• One explanation: tuning problems due to first ever beam extraction from Main Injector to the Fixed Target Lines
• Very high or highly fluctuating spill structure causing exceedingly high instantaneous luminosities

• Main efforts by the Tokyo Tech group to extract as much as possible tracks out of “SPLAT” events
• Main Strategies:
  • Inhibit/Veto schemes
  • Intelligent Track Selection/Seeding
The structure of the proton is far away from being completely understood.

The mechanisms causing a Flavour Asymmetry of the Nucleon Sea can be of different origin and are not yet completely understood -> More precise data is needed.

SeaQuest is the latest high rate Drell-Yan experiment allowing direct access to the Antiquark Flavour Asymmetry of the Proton.

SeaQuest was successfully commissioned in March & April 2012.

First, preliminary di-muon mass spectrum could be reconstructed.

SeaQuest collaboration is working on strategies how to deal with high Occupancy events (Inhibit formalism, Track Seeding strategies etc.) to re-fine the spectrum statistics.

SeaQuest will be running continuously for 2 years to start its physics program.
Kinematics
(From Fred Olness, CTEQ)

Kinematics in the Hadronic Frame

\[ s = (P_1 + P_2)^2 = \frac{\hat{s}}{x_1 x_2} = \frac{\hat{s}}{\tau} \]

\[ P_1 = \frac{\sqrt{s}}{2} (1,0,0,+1) \quad P_1^2 = 0 \]

\[ P_2 = \frac{\sqrt{s}}{2} (1,0,0,-1) \quad P_2^2 = 0 \]

Therefore

\[ \tau = x_1 x_2 = \frac{\hat{s}}{s} \equiv \frac{Q^2}{s} \]

Fractional energy squared between partonic and hadronic system
Longitudinal Momentum Distributions

Partonic CMS has longitudinal momentum w.r.t. the hadron frame

\[ p_{12} = (p_1 + p_2) = (E_{12}, 0, 0, p_L) \]

\[ E_{12} = \frac{\sqrt{s}}{2} (x_1 + x_2) \]

\[ p_L = \frac{\sqrt{s}}{2} (x_1 - x_2) \equiv \frac{\sqrt{s}}{2} x_F \]

\( x_F \) is a measure of the longitudinal momentum

The rapidity is defined as:

\[ x_{1,2} = \sqrt{\tau} e^{\pm y} \]

\[ d x_1 d x_2 = d \tau dy \]

\[ d Q^2 dx_F = dy d\tau s \sqrt{x_F^2 + 4 \tau} \]
Overview of Models

- **Pauli Blocking**
  (excess up-valence quarks suppresses creation up-anti-up-pair)

- **Meson Cloud in the nucleon-Sullivan Process**
  \[
  \langle P | P \rangle = (1 - a - b) \langle P_0 | P_0 \rangle + a \langle N_0 \pi | N_0 \pi \rangle + b \langle \Delta_0 \pi | \Delta_0 \pi \rangle \ldots
  \]

  \[
  \int_0^1 [ \bar{d}(x) - \bar{u}(x) ] = \frac{2a - b}{3} = 0.10 \rightarrow a = 0.2 = 2b \quad g_A = \int_0^1 [ \Delta u - \Delta d ] dx = \frac{5}{3} - \frac{20}{27} \sqrt{2ab} \rightarrow 1.5
  \]

- **Chiral Quark models – effective Lagrangians:**
  \[
  \langle q| q \rangle = \left[ 1 - \frac{3a}{2} \right] \langle q| q \rangle + \frac{3a}{2} \langle q \pi | q \pi \rangle
  \]

  \[
  \int_0^1 [ \bar{d}(x) - \bar{u}(x) ] = \frac{2a}{3} = 0.10 \rightarrow a = 0.14 \quad g_A = \int_0^1 [ \Delta u - \Delta d ] dx = \frac{5}{3} 3a \rightarrow 1.43
  \]

- **Instantons** (so far no kinematic dependence known…)

- **Statistical Parton Distributions**
"Splat" block scheme formulated
- "Inhibit card" to veto events with large number of hits
- 160ns integration window – count hodoscope hits (is it greater than threshold?)
Why preliminary?

• “Splat” block scheme only applies to back of SeaQuest detector
• High occupancy of hits in the first Tracking Stations
• Strategies to select proper hits:

Reference Vector #1

Reference Vector #2

St2 Sagitta

St1 & St2 Sagitta

Reference Plane

Station3, Layer i

Station2, Layer i

Station1, Layer i

Beam Dump

Beam

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The Track Seeder: In Formulas...

\[ s_i = \frac{q \cdot c_D}{p_z} \quad \text{and} \quad c_{ij} = \frac{s_i}{s_j} = \frac{c_D^i}{c_D^j} = \text{const.} \]

is basically a function \( f(L,B) \), where \( L \) is the arch and \( B \) the magnetic field.

In the following the ratio St1-Sagitta/St2-Sagitta are shown!!!
The Track Seeder: Sagitta Ratios

Pretty clear linear correlation!!!

St1-Sagitta vs. St2-Sagitta: D1U-Projections
Abilene Christian University
Obiageli Akinbule
Brandon Bowen
Mandi Crowder
Tyler Hague
Donald Isenhower
Ben Miller
Rusty Towell
Marissa Walker
Shon Watson
Ryan Wright

Academia Sinica
Wen-Chen Chang
Yen-Chu Chen
Shiu Shiuan-Hal
Da-Shung Su

Argonne National Laboratory
John Arrington
Don Geesaman*
Kawtar Hafidi
Roy Holt
Harold Jackson
David Potterveld
Paul E. Reimer*
Josh Rubin

University of Colorado
Joshua Braverman
Ed Kinney
Po-Ju Lin
Colin West

Fermi National Accelerator Laboratory
Chuck Brown
David Christian

University of Illinois
Bryan Dannowitz
Dan Jumper
Bryan Kerns
Naomi C.R Makins
Jen-Chieh Peng

KEK
Shin'ya Sawada

Ling-Tung University
Ting-Hua Chang

Los Alamos National Laboratory
Gerry Garvey
Mike Leitch
Han Liu
Ming Xiong Liu
Pat McGaughey

University of Maryland
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Betsy Beise
Kaz Nakahara

University of Michigan
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Wolfgang Lorenzon
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RIKEN
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Atsushi Taketani
Yoshinori Fukao
Manabu Togawa

Rutgers University
Lamiaa El Fassi
Ron Gilman
Ron Ransome
Elaine Schulte
Brian Tice
Ryan Thorpe
Yawei Zhang

Texas A & M University
Carl Gagliardi
Robert Tribble

Thomas Jefferson National Accelerator Facility
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