Measurement of light-antiquark flavor asymmetry by Drell–Yan experiment SeaQuest at Fermilab

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on behalf of the SeaQuest collaboration

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Introduction
Antiquark Flavor Asymmetry

Research on the structure of the proton

- Gluon splitting: Flavor Independent $\bar{u} = \bar{d}$
- NMC Experiment (DIS) @ CERN (1991)

$$\int_0^1 \bar{d}(x) dx > \int_0^1 \bar{u}(x) dx$$

- NA51 Experiment (Drell–Yan) @ CERN
  - Significant Flavor Asymmetry $\bar{d}/\bar{u} = 1.96$ @ $x = 0.18$
- E866 Experiment (Drell–Yan) @ Fermilab
  - $x$-dependence of $\bar{d}/\bar{u}$ @ $0.015 < x < 0.35$
    - Significant Flavor Asymmetry $\bar{d}/\bar{u} \sim 1.7$ @ $x \sim 0.2$
    - $\bar{d}/\bar{u} < 1.0$ @ $x \sim 0.3$?
      - with large stat. uncertainty
      - No theories can reproduce

$x$ : Bjorken $x = \frac{P_{\text{parton}}}{P_{\text{proton}}}$

(@ high energy)

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Models for $\bar{d}/\bar{u}$

- **Pauli Blocking**
  - $g \rightarrow u\bar{u}$ is suppressed compared to $g \rightarrow d\bar{d}$ ($p = uud$)
  - Only few % effect [NPB149, 497 (1979)]

- **Statistical model** [NPA948, 63 (2016)]
  - Fermi (quarks) and Bose (gluons) statistics

- **Meson cloud model** [PRD58, 092004 (1998)]
  - $|p\rangle = |p_0\rangle + \alpha|N\pi^+\rangle + \beta|\Delta\pi^-\rangle + \gamma|\Lambda K\rangle + \cdots$
    - $N\pi^+ = (udd)(u\bar{d})$
    - $\Delta\pi^- = (uud)(d\bar{u})$
    - $\alpha > \beta$
    - $\rightarrow \bar{d} > \bar{u}$

- etc...

SeaQuest will provide the new data points ($0.1 < x < 0.45$) and it is important to understand the structure of the proton!
Drell–Yan experiment

- Performed at Fermilab (Illinois, US)
  - Main Injector
    - $120 \text{ GeV} (\sqrt{s} \sim 15 \text{ GeV})$ proton beam
    - 5 seconds of beam is provided every 60 seconds (other 55 seconds for neutrino experiments)
    - $53 \text{ MHz}$ beam bunch, $\sim 40k$ protons in a bunch

- Topics
  - **Antiquark Flavor Asymmetry**
  - Nuclear dependence
  - Angular Distribution
  - Dark Photon Search
Collaboration List

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**Academia Sinica**

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*Co-Spokespersons
Drell–Yan Process

- Cross section \((p + p, \text{Leading order})\)

\[
\frac{d^2 \sigma}{dx_{\text{target}} dx_{\text{beam}}} = \frac{4\pi \alpha^2}{9x_{\text{target}}x_{\text{beam}}} \frac{1}{s} \sum_i e_i^2 [q_i(x_{\text{beam}})\bar{q}_i(x_{\text{target}}) + \bar{q}_i(x_{\text{beam}})q_i(x_{\text{target}})]
\]

- An antiquark is always involved
  - \(\bar{q}(x_{\text{beam}})q(x_{\text{target}})\) vanishes in forward detection \((x_{\text{beam}} \gg x_{\text{target}})\)
    - Access antiquarks in target proton and quarks in beam proton
- No strong interaction in final state
  - Able to measure initial state effect
- Final state dimuons are measured in SeaQuest

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SeaQuest Spectrometer

- Targets: LH₂, LD₂, C, Fe, W
- Hadron Absorbers (stop beam, muon identification)
- Magnets (focussing, momentum determination)
- 4 tracking stations, consist of
  - Hodoscopes
  - Drift Chambers (St. 1-3) or Prop. Tubes (St. 4)

Mass distribution fitted with estimated components

Well fitted:
- Detectors & tracking tool work as expected
- Drell–Yan can be selected with mass > 4.2 GeV/c²
Timeline

### Status of Data Taking

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event</th>
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<tbody>
<tr>
<td>2011</td>
<td>08</td>
<td>Finish spectrometer construction</td>
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<tr>
<td>2012</td>
<td>03-04</td>
<td>Commissioning data taking (Run I)</td>
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<td>05-</td>
<td>Detector upgrade</td>
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<tr>
<td>2017</td>
<td>–07</td>
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- Finished data taking (2017.07)
- Recorded protons on targets: $1.4 \times 10^{18}$
- Status in FY2017
  - $0.3 \times 10^{18}$
  - Wider St. 1 chamber:
    - 40% more effective for large $x$ ($\sim 0.4$)
Extract $\bar{d}/\bar{u}$

**Basic Idea**

\[
\frac{\sigma_{pd}(x)}{2\sigma_{pp}(x)} \approx \frac{1}{2} \left[ 1 + \frac{\bar{d}(x)}{\bar{u}(x)} \right]
\]

Drell–Yan cross section ratio is proportional to $\bar{d}/\bar{u}$
with $x_{\text{beam}} \gg x_{\text{target}}$

- Cross section ratio: $\frac{\sigma_{pd}}{2\sigma_{pp}} = \frac{1}{2} \left( \frac{N_D \cdot C_D}{P_D} \right) \left/ \left( \frac{N_H \cdot C_H}{P_H} \right) \right.$
  - Number of dimuons ($N$)
  - Background and reconstruction efficiency corrections ($C$)
  - Normalization with number of nucleons in beam and target ($P$)

- Convert $\sigma_{pd}/2\sigma_{pp}$ to $\bar{d}/\bar{u}$
  \[
  \frac{d^2 \sigma}{dx_{\text{target}}dx_{\text{beam}}} = \frac{4\pi \alpha^2}{9x_{\text{target}}x_{\text{beam}}} \frac{1}{s} \sum_i e_i^2 [q_i(x_{\text{beam}})\bar{q}_i(x_{\text{target}}) + \bar{q}_i(x_{\text{beam}})q_i(x_{\text{target}})]
  \]
  LO Drell–Yan cross section is used for extracting $\bar{d}/\bar{u}$
**$\bar{d}/\bar{u}$ Preliminary Result**

**Systematic uncertainty**
- H contamination in LD
- background
- hit-rate dependence of reconstruction efficiency
- uncertainty from CT10 PDF (cross section ratio $\rightarrow \bar{d}/\bar{u}$)

**Note:** Nuclear corrections for deuterium have not yet been applied.

**Statistics**
- LH$_2$: 17951 dimuons,
- LD$_2$: 20284 dimuons

**SeaQuest Preliminary Result (LO)**
- $\bar{d}/\bar{u} > 1.0$ @ $0.10 < x < 0.45$
- $\bar{d}/\bar{u} = 1.0$ @ $0.45 < x < 0.58$
  within stats. error

**Comparison with NA51, E866**
- $0.1 < x < 0.24$: well consistent
- $x > 0.24$: SeaQuest $>$ E866 ?
  - Difference of $Q^2$?
    - No effect
  - Difference of PDF sets?
    - No effect
Toward Final Results
Difficulties in Current Analysis?

- Reconstruction efficiency effect
  - Reconstruction efficiency decreases as intensity increases (rate-dependent)

- Combinatorial background
  - Example: Single muon coming from $\pi$ + single muon from Drell–Yan
  - Estimated with event mixing method
    - Mix muons from different events
  - Background would be rate-dependent

How to remove these effects?

- Basic Idea: These effects should vanish at “zero” intensity
Extrapolation Method

- Cross-section ratio as a function of intensity
- Extrapolate the data to “Zero” intensity
- **Intercept value is “correct” cross-section ratio**
  - No reconstruction efficiency effect
  - No combinatorial background

**Difficulties of this method?**

- Fitting shape?
- Validity of the method?
- How to extract $\bar{d}/\bar{u}$?

*Investigation is in progress...*
SeaQuest aims to investigate the structure of the proton using Drell–Yan process.

Drell–Yan process is sensitive to the antiquark distributions. Suitable for the investigation of the antiquark flavor asymmetry.

Antiquark flavor asymmetry is important to understand the structure of the proton.

SeaQuest finished the data taking (2012-2017).

The preliminary results from FY2015 were released.

- $\bar{d}/\bar{u} > 1.0 @ 0.10 < x < 0.45$,
- $\bar{d}/\bar{u} = 1.0 @ 0.45 < x < 0.58$

- Further investigation of the discrepancy between E866.

Works for final results are in progress.

- New method: Extrapolation method
- Resolving the difficulties of this method. Final results will be released soon!