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

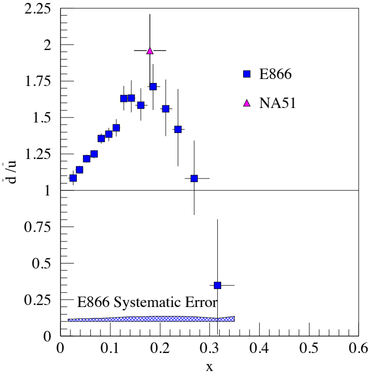
- Gluon splitting: Flavor Independent $\bar{u} = \bar{d}$
- NMC Experiment (DIS) @ CERN (1991)

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

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

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

(@ high energy)



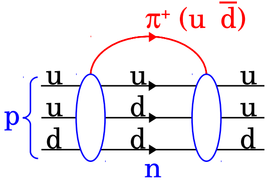
Models for $\bar{d}/\bar{u}$

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

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

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

  $\to$ $\bar{d} > \bar{u}$



- etc...

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

SeaQuest Experiment

SeaQuest Experiment

Drell–Yan experiment

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

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

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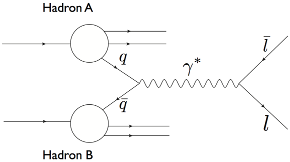
*Co-Spokespersons

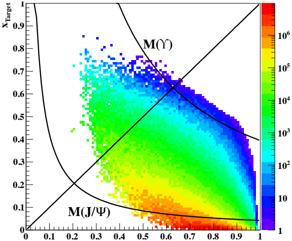
Drell–Yan Process

- Cross section ($p+p$, Leading order)

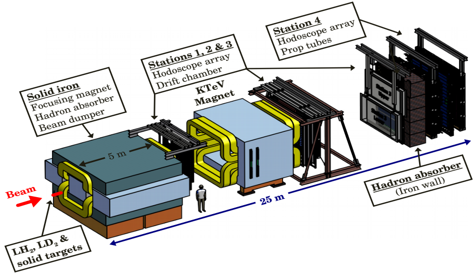
$$\frac{d^2\sigma}{dx_{\text{target}}dx_{\text{beam}}} = \frac{4\pi\alpha^2}{9x_{\text{target}}x_{\text{beam}}}\frac{1}{s}\sum_i e_i^2[q_i(x_{\text{beam}})\bar{q}_i(x_{\text{target}}) + \bar{q}_i(x_{\text{beam}})q_i(x_{\text{target}})]$$



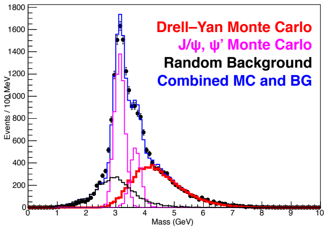
- An antiquark is always involved
- $\bar{q}(x_{\text{beam}})q(x_{\text{target}})$ vanishes in forward detection ($x_{\text{beam}} \gg x_{\text{target}}$)
  - Access ***antiquarks in target proton*** and ***quarks in beam proton***
- No strong interaction in final state
  - Able to measure initial state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



SeaQuest Spectrometer

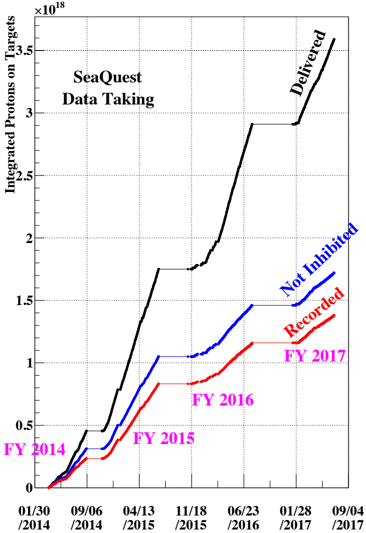


- Targets: LH_2, LD_2, C, Fe, W
- Hadron Absorbers (stop beam, muon identification)
- Magnets (focussing, momentum determination)
- 4 tracking stations, consist of
  - Hodoscopes
  - Drift Chambers (St. 1-3) or Prop. Tubes (St. 4)



- Mass distribution fitted with estimated components
- Well fitted:
  Detectors & tracking tool work as expected
- Drell–Yan can be selected with mass > 4.2 GeV$/c^2$

Timeline



Year	Month	
2011	08	Finish spectrometer construction
2012	03-04	Commissioning data taking (Run I)
	05–	Detector upgrade
2013	11–	Phys. data taking (Run II)
2014	–09	
	11–	Phys. data taking (Run III)
2015	–07	
	10-	Phys. data taking (Run IV)
2016	–08	
	11–	Phys. data taking (Run V)
2017	–07	

- Finished data taking (2017.07)
- Recorded protons on targets: 1.4×10^{18}
- Status in FY2017
  - 0.3×10^{18}
  - Wider St. 1 chamber:
    40% more effective for large x (~ 0.4)

Data Analysis

Extract $\bar{d}/\bar{u}$

Basic Idea

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

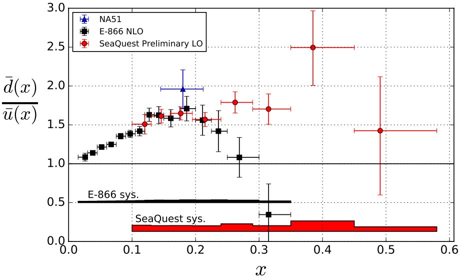
Drell–Yan cross section ratio is proportional to $\bar{d}/\bar{u}$ with $x_{\text{beam}} \gg x_{\text{target}}$

- Cross section ratio: $\dfrac{\sigma_{pd}}{2\sigma_{pp}} = \dfrac{1}{2}\left(\dfrac{N_D \cdot C_D}{P_D}\right) \Big/ \left(\dfrac{N_H \cdot C_H}{P_H}\right)$
  - 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 $\bar{d}/\bar{u}$
  - $\dfrac{d^2\sigma}{dx_{\text{target}}dx_{\text{beam}}} = \dfrac{4\pi\alpha^2}{9x_{\text{target}}x_{\text{beam}}}\dfrac{1}{s}\sum_i e_i^2[q_i(x_{\text{beam}})\bar{q}_i(x_{\text{target}}) + \bar{q}_i(x_{\text{beam}})q_i(x_{\text{target}})]$

    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_2
- 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

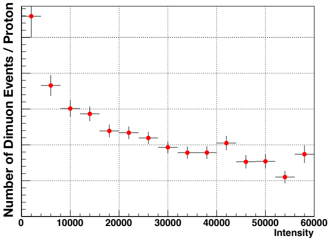
Comparison with NA51, E866

- $0.1 < x < 0.24$: 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)



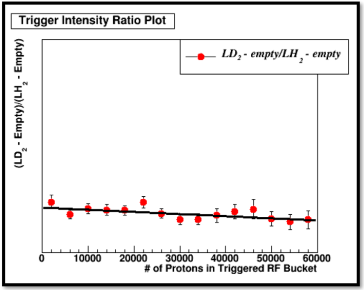
- Combinatorial background
  - Example: Single muon coming from π + single muon from Drell–Yan
  - Estimated with event mixing method
    - ★ Mix muons from different events
  - Background would be rate-dependent

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...

Summary

- 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!

Backup