FNAL ドレル・ヤン実験 SeaQuest による 陽子内の反クォークフレーバー非対称度の測定

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東工大理
Partonic Structure of Proton (Nucleon)

- Quarks, anti-quarks & gluons

The anti-quark distribution is flavor symmetric?
- Strong force is independent of flavor
- Splittings of $g \rightarrow u\bar{u}$ & $g \rightarrow d\bar{d}$ occur equally
Anti-Quark Flavor Asymmetry: $\bar{d}/\bar{u}$

- CERN NMC ('90): deep inelastic muon scattering
  - Gottfried Sum: $S_G = 0.2281(65) < 1/3 \implies \int \bar{d}(x)dx > \int \bar{u}(x)dx$
- Measurement of $x$ dependence of $\bar{u}(x)$ & $\bar{d}(x)$: Drell-Yan process
  - CERN NA51 ('94): $\bar{d} > \bar{u}$ at $x \sim 0.18$
  - FNAL E866/NuSea ('98): $\bar{d}(x)/\bar{u}(x)$ for $x \in (0.015, 0.35)$

- $\bar{d}(x)/\bar{u}(x)$ at high $x$ is not well known. Being measured by SeaQuest
  - Statues of data taking & data analysis are presented in this talk

$70\%$ asymmetry!
Measurement of $\bar{d}(x)/\bar{u}(x)$ with Drell-Yan Process

- Drell-Yan process: $p + p \rightarrow \gamma^* \rightarrow \mu^+ + \mu^-$
  - Invariant mass: $M^2 = x_{\text{beam}} x_{\text{target}} s$
  - Rapidity: $\exp Y = \sqrt{x_{\text{beam}}/x_{\text{target}}}$
  - $x_{\text{beam}} = \frac{M}{\sqrt{s}} e^Y$, $x_{\text{target}} = \frac{M}{\sqrt{s}} e^{-Y}$
  - Cross section at LO:
    $$\frac{d^2 \sigma}{dx_{\text{be}}dx_{\text{ta}}} = \frac{4\pi \alpha^2}{9x_{\text{be}}x_{\text{ta}}} \frac{1}{s} \sum_{q=u,d} e_q^2 \{ q_{\text{be}}(x_{\text{be}}) \bar{q}_{\text{ta}}(x_{\text{ta}}) + \bar{q}_{\text{be}}(x_{\text{be}}) q_{\text{ta}}(x_{\text{ta}}) \}$$
  - Only "$q_{\text{be}}(x_{\text{be}}) \bar{q}_{\text{ta}}(x_{\text{ta}})$" survives @ forward rapidity, i.e. quark in beam & anti-quark in target

- Ratio of cross sections with LH2 & LD2 targets
  $$\frac{\sigma_{pd}(x_{\text{ta}})}{2\sigma_{pp}(x_{\text{ta}})} \approx \frac{1}{2} \left( 1 + \frac{\bar{d}(x_{\text{ta}})}{\bar{u}(x_{\text{ta}})} \right)$$

- SeaQuest reveals $\bar{d}(x)/\bar{u}(x)$ at higher $x (\gtrsim 0.3)$ using lower beam energy ($E = 120$ GeV)
E906/SeaQuest Spectrometer

- Targets: LH$_2$, LD$_2$, C, Fe, W
- Focusing magnet (FMag) & Tracking magnet (KMag)
- Iron inside FMag, as hadron absorber & beam dump
• A typical Drell-Yan event (top view) ... mass = 6 GeV, \( \theta_{\mu^+} = 90^\circ, \phi_{\mu^+} = 0^\circ \)

Detection of dimuons

○ Station 1-3 : Tracking with drift chambers
○ Station 4 : Particle identification with drift tube
○ Momenta of detected muons are 40 GeV/c on average
Status of Data Taking

• Data-taking periods

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event</th>
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</thead>
<tbody>
<tr>
<td>2012</td>
<td>03-04</td>
<td>1st data taking (commissioning)</td>
</tr>
<tr>
<td>2013</td>
<td>11-</td>
<td>2nd data taking (10 months)</td>
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<tr>
<td>2014</td>
<td>11-</td>
<td>3rd data taking (8 months)</td>
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<tr>
<td>2015</td>
<td>10-</td>
<td>4th data taking (10 months)</td>
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<tr>
<td>2016</td>
<td>12-</td>
<td>5th data taking (7 months)</td>
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• Beam protons on targets
  ○ $1.4 \times 10^{18}$ recorded
  ○ $0.6 \times 10^{18}$ analyzed for preliminary $\bar{d}/\bar{u}$

• New data taken in FY2017
  ○ $0.3 \times 10^{18}$ recorded
  ○ Wider chamber acceptance at St. 1
    $\implies$ 40% more events at high $x$ ($\sim 0.4$)
  ○ Top+Top & Bottom+Bottom events (thanks to faster DAQ)
    $\implies$ 30% more events
Status of Data Analysis

- Measurement of Drell-Yan events
  - LH2 & LD2 targets
    \[
    \frac{\sigma_{pd}(x_{ta})}{2\sigma_{pp}(x_{ta})} \approx \frac{1}{2} \left( 1 + \frac{\bar{d}(x_{ta})}{\bar{u}(x_{ta})} \right)
    \]
  - Invariant mass $\geq 4.2$ GeV

- Correction of event yields for
  - Backgrounds (combinatorial & non-target dimuons)
  - Reconstruction efficiency (due to detector hit rates)

- Extraction of $\bar{d}/\bar{u}$ from $\sigma_{pd}/2\sigma_{pp}$
  - Calculation of $\sigma_{pd}/2\sigma_{pp}$ at LO without assuming $x_{be} \gg x_{ta}$

- Improvements toward final result
  - Parameter tunings
  - Better S/N ratio
  - Better hit-rate dependence
    \[
    \frac{d^2\sigma}{dx_{be}dx_{ta}} = \frac{4\pi\alpha^2}{9x_{be}x_{ta}s} \sum_{q=u,d} e_q^2 \{ q_{be}(x_{be})\bar{q}_{ta}(x_{ta}) + \bar{q}_{be}(x_{be})q_{ta}(x_{ta}) \}
    \]
\( \bar{d}(x)/\bar{u}(x) — \text{SeaQuest Preliminary Result} \)

- Systematic errors
  - H in LD2
  - BG subtraction
  - Tracking efficiency
  - and others

- \( \bar{d}/\bar{u} > 1 \) was observed even at high \( x \)
- Physical reasons for the difference between SeaQuest & E866 at \( x \sim 0.3 \) are being investigated
- The \( \bar{d}(x)/\bar{u}(x) \) extraction at NLO will be done
Nuclear Effect on Deuteron at SeaQuest

- Theoretical estimates of $\sigma^{pd}/2\sigma^{pp}$
  - PRD86, 094037: Fermi motion & $\pi$ exchange
  - PRD90, 014010: nuclear smearing & off-shell corrections

- Large change by $\pi$ exchange, but large parameter dependence (i.e. $\pi NN$ form factor)
- Not sizable ($\lesssim 5\%$) at $x \lesssim 0.4$
  - for SeaQuest and also E866
- Sizable ($\sim 50\%$) & large model dep. at $x \gtrsim 0.4$
Summary

- Partonic structure of proton
  - Large anti-quark flavor asymmetry, $\bar{d}(x)/\bar{u}(x)$, was observed
  - SeaQuest measures $\bar{d}(x)/\bar{u}(x)$ at high $x$ with Drell-Yan process

- SeaQuest experiment @ Fermilab
  - Recorded $1.4 \times 10^{18}$ protons on targets by July 2017
  - Analyzed $0.6 \times 10^{18}$ protons for preliminary $\bar{d}/\bar{u}$

- Measurement of $\bar{d}(x)/\bar{u}(x)$
  - $\bar{d}(x)/\bar{u}(x) > 1$ was found up to $x = 0.58$
  - The difference from E866 result is being investigated
  - Studies & improvements for final result
    - Better S/N ratio
    - Better hit-rate dependence
    - Nuclear effect on deuteron
    - NLO extraction of $\bar{d}(x)/\bar{u}(x)$