Precise Measurement of $\frac{p_i^+}{p_i^-}$ Ratios in SIDIS

Charge Symmetry Violation in valence quark distribution extraction

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Motivation

Charge symmetry Violation

Charge symmetry (CS) is one special kind of isospin symmetry.

\[
\delta d(x) = d^p(x) - u^n(x), \\
\delta u(x) = u^p(x) - d^n(x).
\]

Londergan, Pang and Thomas PRD54(1996)3154

\[
R_{\text{meas}}^D(x,z) = \frac{4N_{\pi^-(x,z)}^D - N_{\pi^+(x,z)}^D}{N_{\pi^+(x,z)}^D - N_{\pi^-(x,z)}^D} = \frac{4R_Y(x,z) - 1}{1 - R_Y(x,z)} \tag{1}
\]

where \(N_{\pi^\pm}^D(x,z)\) is the yield of \(\pi^\pm\) electroproduction on a deuterium target and the CSV of quark distributions can be extracted.

Factorization

\[
N^{Nh} = \sum_i e_i^2 q_i N_i(x) D_i^h(z)
\]

Impulse Approximation

\[
N_{\pi^\pm}^D(x,z) = N_{\pi^\pm}^p(x,z) + N_{\pi^\pm}^n(x,z)
\]
Formalism
Londergan, Pang and Thomas PRD54(1996)3154

\[ D(z) \ R(x, z) + A(x)CSV(x) = B(x, z) \]

\[ D(z) = \frac{1 - \Delta(z)}{1 + \Delta(z)} \]

\[ \Delta(z) = D_u^\pi^- (z)/D_u^\pi^+ (z) \]

\[ R(x, z) = \frac{5}{2} + R_{\text{meas}}^D \]

\[ CSV(x) = (\delta d - \delta u) \]

\[ A(x) = \frac{-4}{3(u_v + d_v)}, \text{known} \]

\[ B(x, z) = \frac{5}{2} + R_{\text{sea,S}}^D(x, z) + R_{\text{sea,NS}}^D(x), \text{known} \]

Extract simultaneously \( D(z) \) and \( CSV(x) \) from each \( (Q^2, x) \) setting

Factorization test from \( H_2 \) runs

\[ \frac{\sigma_{p}^{\pi^+} - \sigma_{p}^{\pi^-}}{\sigma_{d}^{\pi^+} - \sigma_{d}^{\pi^-}} = \frac{4u + 4\bar{u} + d + \bar{d}}{5(u + \bar{u} + d + \bar{d})} \]

\[ \frac{\sigma_{p}^{\pi^+} + \sigma_{p}^{\pi^-}}{\sigma_{d}^{\pi^+} + \sigma_{d}^{\pi^-}} = \frac{4u_v - d_v}{3(u_v + d_v)} \]
Semi-Inclusive Deep Inelastic Scattering (SIDIS) in Hall C
Electron: HMS, pion: SHMS
Fall 2018 and Spring 2019

- 10.6 GeV beam, LD$_2$(10 cm), LH$_2$(10 cm), Al-dummy
- HMS angle 13°-21°, 4.4-6.4 GeV, electrons
- SHMS angle 11°-21°, 1.7-4.5 GeV, π$^+$ / π$^-$
Data Analysis

Kinematic Cut

4 $z$ measurements (0.4, 0.5, 0.6, 0.7) for each $x, Q^2$ setting.

- $Q^2 = 4.0 GeV^2, x = 0.35, 0.4, 0.45, 0.5$
- $Q^2 = 4.75 GeV^2, x = 0.45, 0.5, 0.55, 0.6$
- $Q^2 = 5.5 GeV^2, x = 0.5, 0.55, 0.6, 0.65$

DIS cut: Invariant mass squared

$$W^2 = (P + k - k')^2 = M^2 + \frac{1-x}{x} Q^2$$

SIDIS cut: Mass of the unobserved final state squared

$$W'^2 = (P + k - k' - P_h)^2 = M^2 + Q^2 \frac{1-x}{x} + M_h^2 - 2 \cdot (z + 1) \frac{Q^2}{2 \cdot M_x}$$

DIS: $W^2 \ GeV^2$ and SIDIS: $W'^2 > 2.8 \ GeV^2$
\[ \langle x \rangle = 0.5, \langle Q^2 \rangle = 5 GeV^2, \langle z \rangle = 0.5 \]

Data yield

\[ Y_{corr}^D = \frac{N_{\text{pions}}}{Q \varepsilon_t \varepsilon_{LT} \varepsilon_{PID}} \]

Radiative correction: \( RC = \frac{Y_{SIMC,\text{noradia}}}{Y_{SIMS,\text{radia}}} \)

Backgrounds from SIMC:
- \( Y_{exc} \): Exclusive radiative backgrounds
  \( D(e, e'\pi^\pm)n(p)\gamma \)
- \( Y_{delta} \): Delta radiative backgrounds
  \( D(e, e'p)\pi \)
- \( Y_\rho \): Diffractive \( \rho \) \( D(e, e'\rho \to \pi^+\pi^-) \)

\[ Y_D(x, z) = RC(Y_{corr}^D - 0.245 Y_{\text{Dummy}} - Y_{exc} - Y_{delta}) \]
Model dependence

\[ D(z) \ R(x, z) + A(x) CSV(x) = B(x, z) \]

\[ A(x) = \frac{-4}{3(u_v + d_v)} \]

\( A(x) \) is calculated from Parton Distribution Function. Plot is calculated from JAM20 PDF.
Model dependence

\[ D(z) \ R(x, z) + A(x) CSV(x) = B(x, z) \]

\[ B(x, z) = \frac{5}{2} + R_{sea-S}^{D}(x, z) + R_{sea-NS}^{D}(x) \]

\[ R_{sea-NS}^{D} = \frac{5(\bar{u}^{p}(x) + \bar{d}^{p}(x))}{[u^{p}(x) + d^{p}(x)]} \]

\[ R_{sea-S}^{D} = \frac{\Delta s(z)[s(x) + \bar{s}(x)]/(1 + \Delta(z))}{[u^{p}(x) + d^{p}(x)]} \]

\[ \Delta s(z) = \frac{D_{s}^{-}(z) + D_{s}^{+}(z)}{D_{u}^{+}(z)} \]

cteq6 PDF and JAM20 FF
$R_{meas}^D$ from data

\[ D(z) \, R(x, z) + A(x) \, CSV(x) = B(x, z), \, R(x, z) = \frac{5}{2} + R_{meas}^D(x, z) \]

$R_{meas}^D(x, z) \text{ for } \langle Q^2 \rangle = 4 \text{GeV}^2$

projected on $z$ axis.

All variables are bin center corrected.

For each of $(Q^2, x, z)$, weighted average are taken for the overlap of the different group of runs.
Fragmentation ratio and CSV extraction

\[
D(z) \ R(x, z) + A(x)CSV(x) = B(x, z)
\]

\[
\Delta(z) \equiv \frac{D_u^-(z)}{D_u^+(z)} = z^\alpha (1-z)^\beta
\]

\[
CSV_x \equiv \delta d - \delta u = x^a (1-x)^b (x-c)
\]

constrain: \[ \int_0^1 CSV(x) dx = 0 \]

\[
c = \frac{\int_0^1 x^{(a+1)} (1-x)^b}{\int_0^1 x^a (1-x)^b} = \frac{B(a + 2, b + 1)}{B(a + 1, b + 1)}, B(x, y) = \frac{\Gamma(x)\Gamma(y)}{\Gamma(x+y)}
\]

\[
R_{fit}^D(x, z) = \frac{B(x, z) - A(x)CSV(x)}{D(z)} - \frac{5}{2}
\]
Diffractive $\rho$ background subtraction

\[ D(z) \, R(x, z) + A(x)CSV(x) = B(x, z) \]

Assumption:

1. The $\rho$ decay into pions are charge symmetric: $N_{\pi^-}^\rho = N_{\pi^+}^\rho$

2. The $\rho$ subtraction for $\pi^+$ runs and $\pi^-$ runs are same

\[ Y_{corr}^{D\pi^-} = Y^{D\pi^-} + \gamma Y_{\pi^-}^\rho \]
\[ Y_{corr}^{D\pi^+} = Y^{D\pi^+} + \gamma Y_{\pi^-}^\rho \]

\[ \delta R_D^\rho = \delta R_D^\rho(\gamma, Y_{\pi^-}^\rho, Y^{D\pi^+}, Y^{D\pi^-}) \]

For standard $\rho$ subtraction, $\gamma$ is -1
Results after standard $\rho$ background subtraction

\[ \Delta(z) \equiv D_u^{-}(z)/D_u^{+}(z) = z^{\alpha}(1 - z)^{\beta} \]

\[ D(z) R(x,z) + A(x) CSV(x) = B(x,z) \]

From the fitting result $\Delta(z)$, CSV can be calculated for each kinematic point. Weighted average are taken for overlap.
Results

Residual for standard $\rho$ background subtraction

$\chi^2 / n_{\text{dof}} = 479.3 / 342$

$\alpha = 0.239 \pm 0.028$

$\beta = 1.230 \pm 0.065$

$a = 2.273 \pm 0.568$

$b = 0.116 \pm 0.547$

$\gamma = 1.000 \pm 0.010$

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**H₂ runs results**

H₂ runs are taken for some kinematic to test the assumption of factorization.

\[
\frac{\sigma_{p}^{\pi^+} - \sigma_{p}^{\pi^-}}{\sigma_{d}^{\pi^+} - \sigma_{d}^{\pi^-}} = \frac{4u + 4\bar{u} + d + \bar{d}}{5(u + \bar{u} + d + \bar{d})}
\]

\[
\frac{\sigma_{p}^{\pi^+} + \sigma_{p}^{\pi^-}}{\sigma_{d}^{\pi^+} + \sigma_{d}^{\pi^-}} = \frac{4uv - dv}{3(uv + dv)}
\]
Future work

- Improve and update $\rho$ background subtraction
- Systematic Uncertainty
- Finalize the analysis cuts and data set, cross check with Hem’s ratio
- Fit with more data from PtSIDIS experiment
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Thank you!
Backups
Model dependence

Parton Distribution Functions

Fragmentation Functions
Results after different diffractive $\rho$ subtraction

\[
\Delta(z) \equiv D_u^{-}(z)/D_u^{+}(z) = z^\alpha (1 - z)^\beta
\]

\[
\delta R^D_\rho = \delta R^D_\rho (\gamma, N^{neg-\rho}, N^{\pi^+}, N^{\pi^-})
\]

\[
\gamma \text{ ranges 20\%}. \text{ Doesn’t change too much}
\]